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Department of
Water Resources

Evaluation of Ground Water Resources Sonoma County. Volume 5: Alexander Valley and Healdsburg Area

Department of Water Resources
in cooperation with the Sonoma County Water Agency

Bulletin 118-4
June 1983

A high-capacity irrigation well northwes of Jimtown in Alexander Valley. Yields from such wells can reach 3,000 gallons pe minute. Sprinklers serve the dual purpose c irrigation and frost control. A diesel moto (behind the screen) drives the pump shaft shown in the center. The well casing is th vertical pipe immediately to the left of th light-colored tank in the center of the photo The light-colored pipe at the left is a san seperetor.

Department of Water Resources
in cooperation with the
Sonoma County Water Agency

Bulletin 118-4

Evaluation of Ground Water Resources: Sonoma County

Volume 5 Alexander Valley and Healdsburg Area

June, 1983

Gordon K. Van Vleck
Secretary for Resources

The Resources Agency

George Deukmejian
Governor

State of California

Howard H. Eastin
Acting Director

Department of Water Resources

FOREWORD

Ground water plays an important role in Sonoma County. As the population of this North Bay county has increased over the last 30 years, the use of ground water has increased. Over 15,000 wells are known to exist in the county. These wells are used for domestic and agricultural purposes in rural areas and for municipal and industrial purposes in urban areas.

The Sonoma County Water Agency requested the California Department of Water Resources (DWR) to undertake a cooperative study to estimate the volume of ground water in storage and the recharge potential in the Santa Rosa Plain, Petaluma Valley, Sonoma Valley, and Alexander Valley and Healdsburg area. The study examined alternative ways the ground water resources of the county may be used conjunctively with the Russian River and other surface water sources.

The present study was designed to augment an earlier countywide investigation of geology and hydrology conducted jointly by the Sonoma County Planning Department and DWR. Results of the earlier investigation were published as DWR Bulletin 118-4, Volume 1 (Ford, 1975). The results of this recent study are presented in four volumes. This report is Volume 5 and describes ground water conditions in Alexander Valley and the Healdsburg area. Volume 2 deals with the Santa Rosa Plain, Volume 3 with the Petaluma Valley, and Volume 4 with the Sonoma Valley.

This report on Alexander Valley and the Healdsburg area includes evaluation of: geologic and hydrologic characteristics of the ground water basins; the volume of fresh ground water in the basins; the interconnection of ground water and surface water; and the potential for artificial recharge of ground water.

H. H. Eastin

Howard H. Eastin, Acting Director
Department of Water Resources
The Resources Agency
State of California

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(in separate pocket)

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Chapter 1. INTRODUCTION

Alexander Valley and the Healdsburg area (Figures 1 and 2) have been experiencing a general population increase, as has all of Sonoma County. Because the population has increased, so has the demand for water. Ground water, water stored underground in permeable rock or soil formations, plays an important role in meeting this demand. More than 15,000 water wells have been identified in Sonoma County, of which about 1,600 are in Alexander Valley and the Healdsburg area. Ground water accounts for about 60 percent of the total water demand for the middle Russian and Dry Creek units of the Russian River service area (Finlayson, 1980; see references at end of report).

Ground water is used for domestic, municipal, industrial, and agricultural purposes. The cities of Cloverdale and Healdsburg rely principally on ground water to meet municipal water needs.

To obtain adequate information for preparation of a water resources development plan in Sonoma County, the Department of Water Resources entered into an agreement with Sonoma County Water Agency to study the water resources of the county. The study evaluates the hydrologic characteristics of the area and the effects of increased use on the ground water resource, and it offers suggestions on the conjunctive use of ground and surface water supplies.

Sonoma County Water Agency requested that the study:

° Evaluate the geologic and hydrologic characteristics of the various ground water basins and estimate their physical, economic, and operational potential.

° Evaluate the potential yield of the ground water basin and possible changes in water quality resulting from optimum pumping.

° Evaluate potential for artificial recharge of the ground water basin.

° Present a range of alternative plans of operation that can be used as a guide by local agencies to determine use of ground water in conjunction with surface supplies.

The cooperative study accomplished two goals. First, the study provided ground water data that Sonoma County Water Agency needs to develop water management guidelines and that the Department of Water Resources needs to evaluate the extent of the ground water resource for use in statewide planning. Second, the cooperative study assures that planning will be based on local conditions and that local agencies will be involved in the effort and be acquainted with the conclusions and with the facts on which those conclusions are based.

Location of the Study Area

Alexander Valley extends southward from the Sonoma-Mendocino county line to about 1.6 kilometres (1 mile) south of Barnes Creek, a distance of about 32 kilometres (20 miles) (Figure 2). Cloverdale Valley is included in Alexander Valley. The Russian River flows through the entire length of Alexander Valley. The valley has a maximum width of 2.4 kilometres (1.5 miles) and encompasses about 10 700 hectares (26,500 acres) of flat land. The total area of water-bearing formations is somewhat

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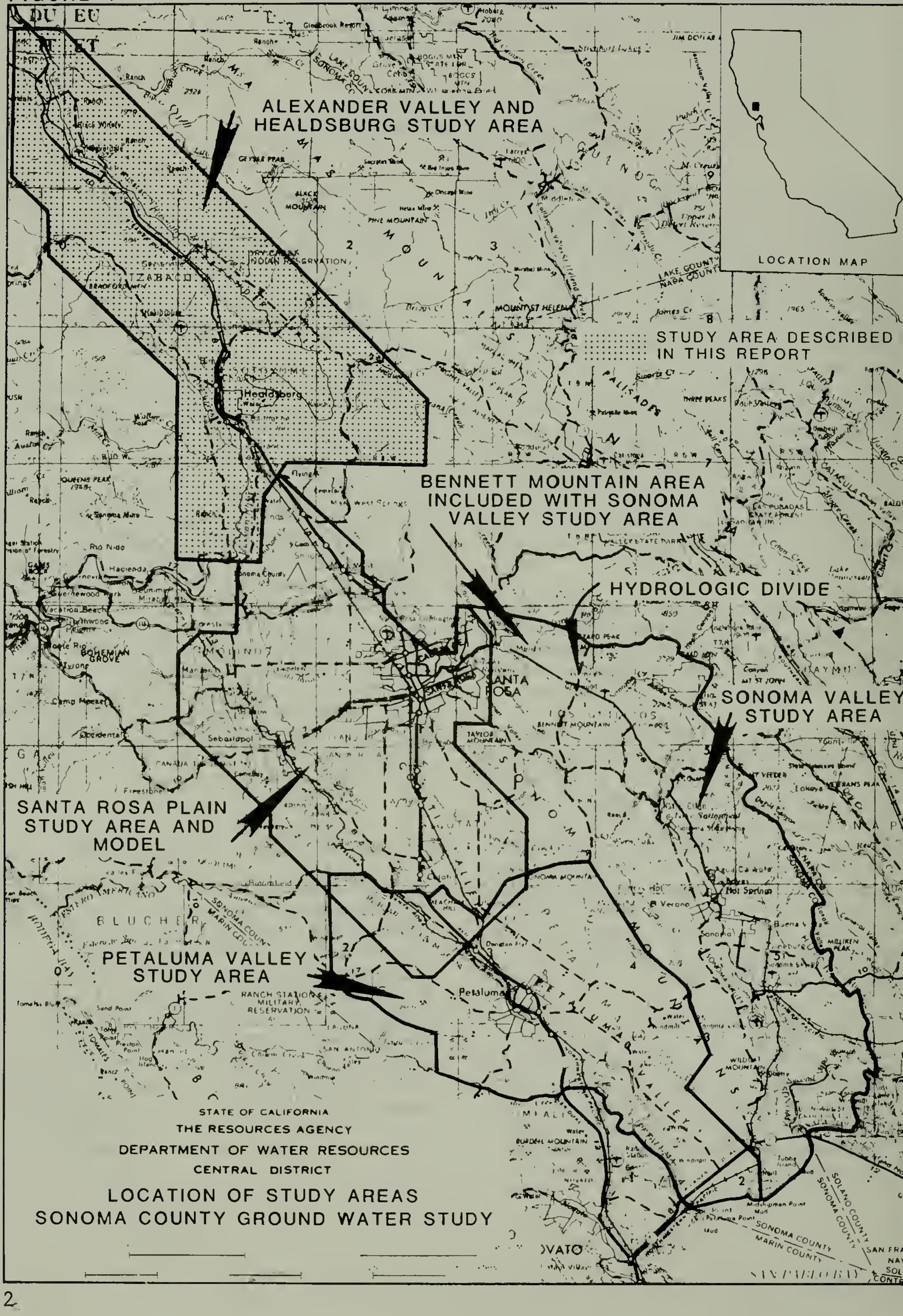
FIGURE 1



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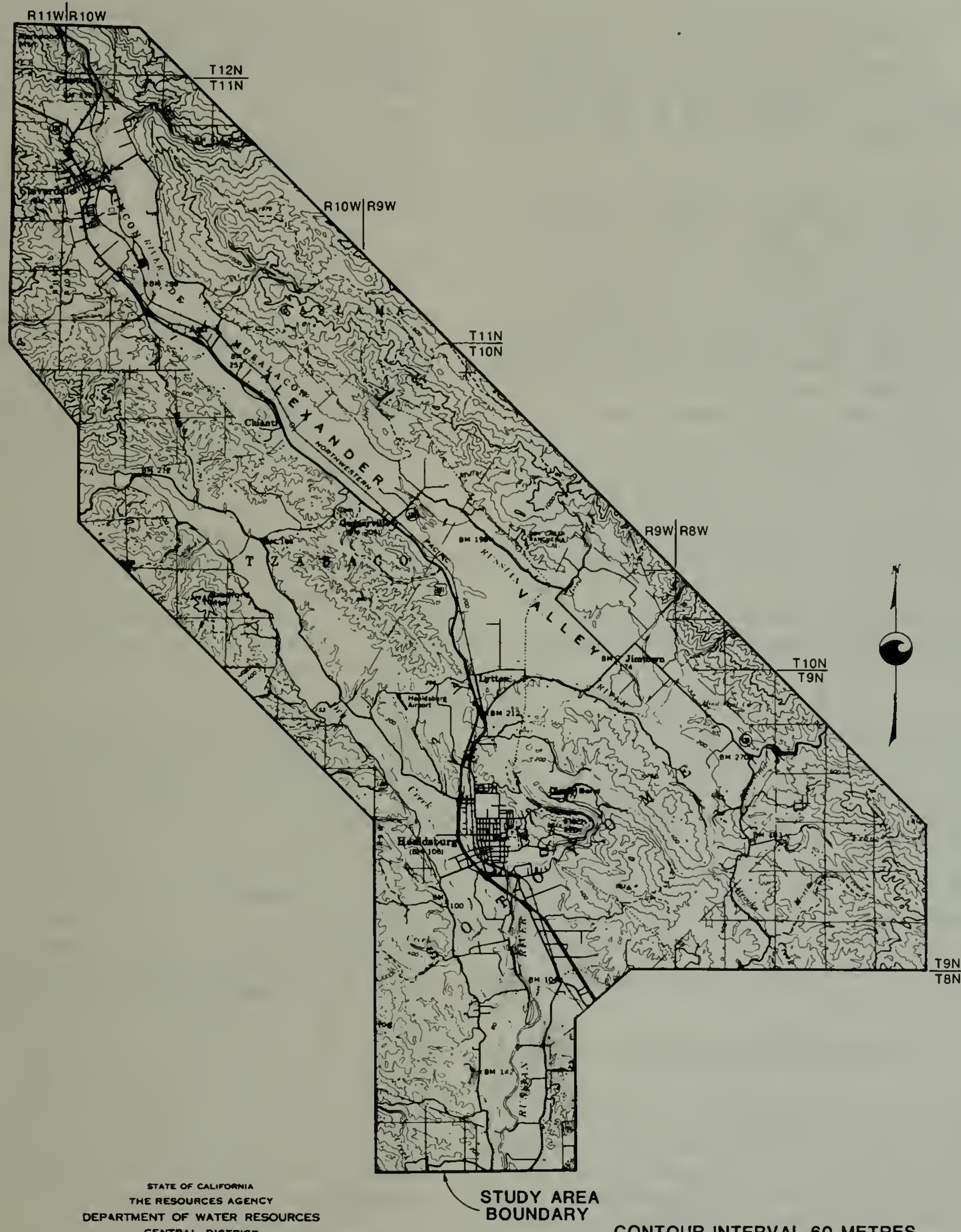
LOCATION OF STUDY AREAS
SONOMA COUNTY GROUND WATER STUDY



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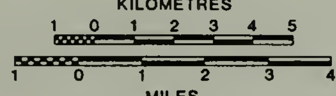
ALEXANDER VALLEY AND HEALDSBURG AREA
SONOMA COUNTY GROUND WATER STUDY

STUDY AREA

CONTOUR INTERVAL 60 METRES
(200 FEET)



larger because the valley floor is locally bounded by low hills consisting of unconsolidated water-bearing sediments. The Russian River is joined by a principal tributary, Big Sulphur Creek, at the north end of Cloverdale Valley.

The Healdsburg area includes the flood plain of the Russian River, as well as adjacent areas outside the flood plain, and extends from the confluence of School House Creek and Dry Creek at the north to Lafayette School and the U. S. Government Reservation in Healdsburg to the south. Russian River passes through only a small portion of the valley that constitutes the Healdsburg area. The entire area, which includes Dry Creek Valley, encompasses about 8 100 hectares (20,000 acres) and trends in the same general direction as Alexander Valley. The width of the Healdsburg area ranges from less than 1 kilometre to 3 kilometres (0.5 to 2 miles), and the length is about 16 kilometres (10 miles). It is widest at the confluence of Russian River and Dry Creek.

The entire study area is included in the Sonoma County ground water basin (Peters, 1980). Figure 2 shows the study area boundary. The boundary of the two ground water sub-basins, Alexander Valley and Healdsburg area, is generally determined by the boundary of the alluvium and river channel deposits, except where some older water-bearing sediments occur at the surface (see Figure 10, on page 33, and Plate 1).

Previous Related Investigations

Previous investigations related to the ground water resources in Alexander Valley and the Healdsburg area have been limited chiefly to collecting data on specific water resource problems. The earliest published report dealing with the water resources of the area (Waring, 1915) summarized the characteristics of several springs in Sonoma County.

The first comprehensive study of the geology of Sonoma County was by Weaver (1949). Subsequently, the U. S. Geological Survey published three water-supply papers dealing with ground water geology of various parts of the county (Cardwell, 1958; Cardwell, 1965; and Kunkel and Upson, 1960). Cardwell (1965) included the entire Russian River watershed.

Current Investigation

For this study, data were collected from selected water wells, including most of the irrigation, public supply, and large-draft industrial wells. The water levels in selected wells were measured periodically to determine the magnitude and characteristics of the fluctuations in ground water levels.

To simplify compilation and evaluation of hydrologic data, the area was divided along township, range, and section lines to form 130 to 260 hectare (320 to 640 acre) cells. All hydrologic data were then evaluated by cells.

To determine the total volume of ground water in storage and the total storage space available to receive recharge, water well logs were used to develop geologic cross sections. The well log information on types of materials encountered in each well was coded as input to a computer program, described in Chapter 4. This program averages the log information by cells to estimate total ground water storage capacity for each cell. When combined with fall 1980 water level information, the total volume of ground water in storage and the remaining unsaturated storage space available to receive recharge were determined for fall 1980. Water quality data were tabulated and calculated to determine whether selected mineral constituents exceed recommended limits.

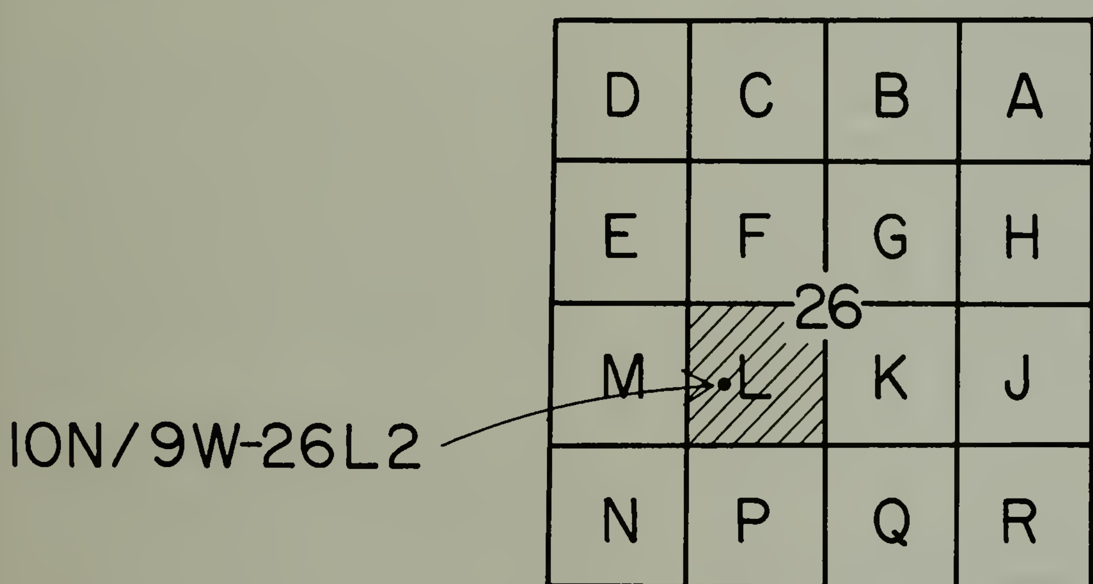
Soil maps developed by the U. S. Department of Agriculture Soil Conservation Service (Miller, 1972) were evaluated according to their combined land slope and soil permeability. Those soils on slopes less than 15 percent and

having a permeability greater than 1.5 centimetre (0.6 inch) per hour have been tentatively classified as natural recharge areas (after Muir and Johnson, 1979).

The well numbering system used in this report is based on the rectangular system of subdividing public land. Many valley areas are portions of land grants and have never been formally subdivided according to the U. S. Public Land Grid. For reference in locating water wells and other features, these areas have been subdivided by extending the section lines from adjacent areas. A reference set of maps showing these extensions is on file at the Department of Water Resources and can be used by interested persons.

A State well numbering system has two basic parts: township and range location, and section location. For example, well 10N/9W-26L2 (Figure 3) is in Township 10 North, Range 9 West, and Section 26. Each section is subdivided into 16 quarter-quarter sections of 16 hectares (40 acres) each. Each 16-hectare tract is identified by a letter designation. This particular well is in tract "L", which also can be described as the northeast quarter of the southwest quarter of Section 26. The final number is the sequential number of the well within the particular 16-hectare tract.

FIGURE 3



WELL NUMBERING SYSTEM

Chapter 2. CONCLUSIONS AND RECOMMENDATIONS

This study of ground water resources in Alexander Valley and the Healdsburg area has led to the following conclusions and recommendations.

Conclusions

- The alluvium and river channel deposits are the principal sources of ground water in wells. The Glen Ellen Formation is of secondary importance, while the older formations and terrace deposits provide lesser amounts for some domestic water supplies. Water wells in the alluvium generally do not exceed 18 metres (60 feet) total depth and pump between 760 to 1 890 litres (200 to 500 gallons) per minute.

- Most principal aquifers in the Healdsburg area appear to be hydraulically connected with the Russian River. It is probable that shallow wells close to the Russian River and Dry Creek get water directly from the adjacent stream as the result of stream water entering the ground water basin during the dry part of the year while water flows into the river from the ground water basin during the rest of the year.

- If the flow of the Russian River is seriously curtailed, shallow wells close to the river could be affected.

- The total volume of ground water in storage in fall 1980 was 1.22 million cubic dekametres (992,000 acre-feet). This represents the total storage in both Alexander Valley and the Healdsburg area. The total storage capacity of the study area is 1.65 million cubic dekametres (1.34 million acre-feet), according to TRANSCAP. There is probably a larger storage capacity, especially in the Glenn Ellen Formation, but deep well data are lacking to verify this.

- Based on TRANSCAP, the volume of storage available to accept recharge was 283 700 cubic dekametres (230,000 acre-feet) in fall 1980. This represents 23 percent of the total ground water in storage in fall 1980 and 17 percent of the total storage capacity.

- Water level fluctuations for the wells being monitored have averaged less than 3 metres (10 feet). This fluctuation reflects only seasonal withdrawals and recharge. Well hydrographs indicate no long-term declines, and no overdraft exists at this time. Because the basins are essentially "full", an artificial recharge program to increase the volume of ground water in storage is not needed now.

- Ground water pumpage can probably be increased with little or no adverse effect in all areas except in the higher elevations where wells tap the Franciscan Complex. Ground water in the rocks of the Franciscan Complex is limited in quantity, and the rocks themselves have very low permeabilities and specific yields.

- Ground water in the study area is hard, bicarbonate, and generally suitable for all uses. The dissolved solids content ranges from 80 to 680 milligrams per litre (mg/L). Hardness ranges from 14 to 230 mg/L. Concentration of iron is low, generally less than 0.1 mg/L.

- Ground water is used for agricultural, industrial and domestic, and municipal supply.

Recommendations

- Continue ground water level monitoring so that estimates of ground water in storage can be improved and any changes in the ground water table can be detected.

- Considering the proximity of shallow wells to the Russian River and its tributaries and the assumption that these wells are fed by the streams, severe curtailment of riverflow and water contamination should be avoided if present practices are to continue.

- Examine available data more closely to determine the amount of hydraulic continuity between the riverflow and water wells near the river.

- More accurately define the recharge areas and recharge rates within the study area so that the importance of these areas to the ground water reservoir are understood.

- Establish a program for periodic sampling of water wells for water quality. Constituents for which analyses should be conducted include sodium, salinity, total dissolved solids, nitrate, boron, and hardness.

- Conduct 24-hour, constant rate pump tests at selected locations in the study area to determine aquifer characteristics.

Chapter 3. GEOLOGY AND HYDROLOGY

This chapter presents a brief overview of the ground water geology, hydrology, and soils of Alexander Valley and the Healdsburg area. A detailed description of these subjects has been published in Department of Water Resources Bulletin 118-4, Volume 1 (Ford, 1975).

Two ground water sub-basins exist within the study area boundary. They are Alexander Valley and a valley referred to as the Healdsburg area. The Alexander Valley ground water sub-basin consists of two adjacent ground water reservoirs, Cloverdale Valley in the north and Alexander Valley in the south.

Alluvium is the principal source of ground water in both Alexander Valley and the Healdsburg area. Of secondary importance are the Glen Ellen Formation, alluvial fan deposits, and terrace deposits, although the Glen Ellen Formation is a major source in the southern part of Alexander Valley. In the extreme southern part of the Healdsburg area, wells tap the Merced Formation. Springs and wells in the Franciscan Complex yield small quantities of water along the western flank of the Healdsburg area. The Sonoma Volcanics locally yield water to wells, but their occurrence is limited.

Table 1 summarizes geologic and hydrologic characteristics of these units and their specific yields. Plate 1 shows the areal distribution of these units.

Table 1

SUMMARY OF HYDROLOGIC AND GEOLOGIC UNITS IN ALEXANDER VALLEY AND HEALDSBURG AREA

Geologic Unit	Lithology	Specific Yields	Comments
Franciscan Complex	Includes chert, sandstone, shale, greenstone, serpentine, limestone, and conglomerate.	Very Low (3%)	Poor quality water in thermal areas. Excellent quality water in some cold springs that issue from these rocks.
Dry Creek Conglomerate	Cobbles and boulders of granodiorite, chert, quartz, and greenstone, in an arkosic sandstone matrix.	High (10-20%)	Yields excellent quality calcium bicarbonate water to wells.
Merced Formation	Course- to fine-grained sandstone, with minor amounts of clay and volcanic materials.	Moderate (8-15%)	Good quality water. Large quantities of water may be obtained in thick sections of consolidated sand.
Sonoma Volcanics	Thick section of flows, dikes, plugs, and beds of andesite, rhyolite, basalt, tuff, and related flow rocks.	Variable (0-15%)	Well productivity in the volcanics is highly variable and unpredictable. Warm water is encountered in thermal areas. Generally yields satisfactory quality sodium bicarbonate water.
Glen Ellen Formation	Poorly sorted alluvial fan and flood plain deposits of gravel, sand, silt, and some clay.	Low (3-7%)	Ground water in the formation has a greater range of character than any other formation. Some of the best and some of the poorest quality water is obtained from this formation.
Terrace Deposits	Unconsolidated deposits of sand and gravel.	Moderate (8-15%)	Water quality is generally excellent. Water is a sodium magnesium-bicarbonate type.
Alluvium and River Channel Deposits	Coarse sand, silt, clay, and gravel, and lenses of very fine sand.	High (8-20%)	Minor amounts of methane gas. The formation supplies most of the ground water in the area.

The subsurface distribution of these units has been determined along the cross section lines indicated on Plate 1 and Figure 4A as A-A', B-B', C-C', and D-D'. Figures 4B-E show profiles of the four cross sections. The following paragraphs briefly describe the geologic units.

Franciscan Complex

The Franciscan complex, of Jurassic to Cretaceous age (see Figure 5), is the oldest geologic unit in the study area. The rocks of the Franciscan Formation consist mainly of poorly sorted sandstone and shale, but also include serpentinite, greenstone, chert, and occasionally schist. Greenstone predominates southwest of Dry Creek, but local bodies of shale, chert, sandstone, and serpentinite do occur (Cardwell, 1965).

Numerous faults transect the area and, as a result, the rocks are generally cut by many fractures. Many springs issue from these fractured rocks and supply water to the local tributaries of the Russian River. These springs and wells in the bedrock also supply water for many rural homes near Cloverdale Valley. Well 11N/10W-19F2, which is 102 metres (335 feet) deep, obtains water from fractures in bedrock (Cardwell, 1965). Even though the specific capacity of the well is reportedly low, the well yields are sufficient for domestic use. Because of the low well yields, areas underlain by the Franciscan Complex were not included in calculations of storage capacity.

Dry Creek Conglomerate

The Dry Creek conglomerate, of Cretaceous age, is exposed from Lytton to about 16 kilometres (10 miles) northwest of Lytton. The conglomerate is composed of well rounded cobbles and boulders of granodiorite, porphyry, quartz, chert, and greenstone contained in a matrix of medium to coarse-grained arkosic sandstone (Ford, 1975; Cardwell, 1965). The conglomerate consists of beds up to 30 metres (100 feet) thick (Ford, 1975). The entire formation was estimated by Gealey (1951) to be about 1 500 metres (5,000 feet) thick.

Wells that tap saturated sections of the Dry Creek conglomerate generally produce sufficient quantities of water for domestic purposes. The ground water is apparently contained in pore spaces between uncemented grains and in small fractures. The formation yields water to wells even though the permeability is thought to be low (Cardwell, 1965). Well yields range from 75 to 230 litres (20 to 60 gallons) per minute, with drawdowns from 5 to 30 metres (15 to 100 feet) (Ford, 1975).

Merced Formation

The Merced Formation, generally of Pliocene age, occurs only in the southern part of the Healdsburg area. The formation is composed of unconsolidated to slightly consolidated, fine to medium grained, fossiliferous sand and sandstone, with some gravelly lenses and sandy clay. The formation also contains at least one persistent tuffaceous bed. The Merced Formation ranges in thickness from a few metres to 300 metres (1,000 feet) or more (Cardwell, 1965). A more detailed discussion of the Merced Formation is given in Cardwell (1959), Ford (1975), and Bedrossian (1970).

The Merced Formation generally yields large quantities of water, and further south is an important water-bearing formation. To the south, in the Sebastopol area, some wells in the Merced Formation yield 23 000 litres (600 gallons) per minute, or more (Cardwell, 1965). In the Healdsburg area, however, only small to moderate yields are obtained from wells that tap this formation. A few wells in the Healdsburg area do tap thick sections of unconsolidated sand and yield large quantities of water.

EXPLANATION
FOR GEOLOGIC SECTIONS
(FIGURE 4B–4E)

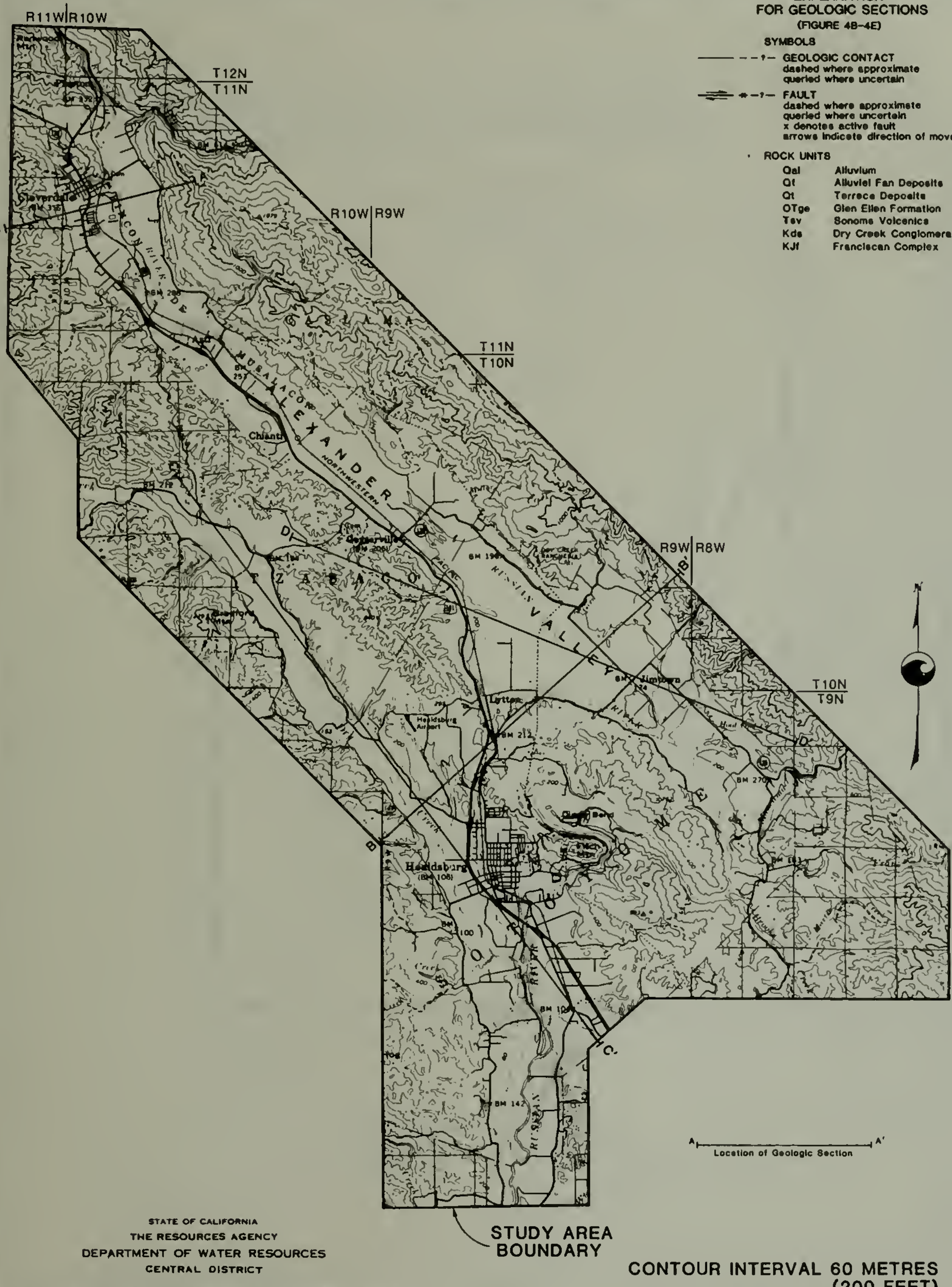
SYMBOLS

GEOLOGIC CONTACT
dashed where approximate
queried where uncertain

FAULT
dashed where approximate
queried where uncertain
x denotes active fault
arrows indicate direction of movement

ROCK UNITS

Qal	Alluvium
Qf	Alluvial Fan Deposits
Qt	Terrace Deposits
QTge	Glen Ellen Formation
Tsv	Sonoma Volcanics
Kds	Dry Creek Conglomerate
KJf	Franciscan Complex



A — A'
Location of Geologic Section

STUDY AREA BOUNDARY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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CENTRAL DISTRICT

ALEXANDER VALLEY AND HEALDSBURG AREA
SONOMA COUNTY GROUND WATER STUDY

INDEX TO GEOLOGIC SECTIONS

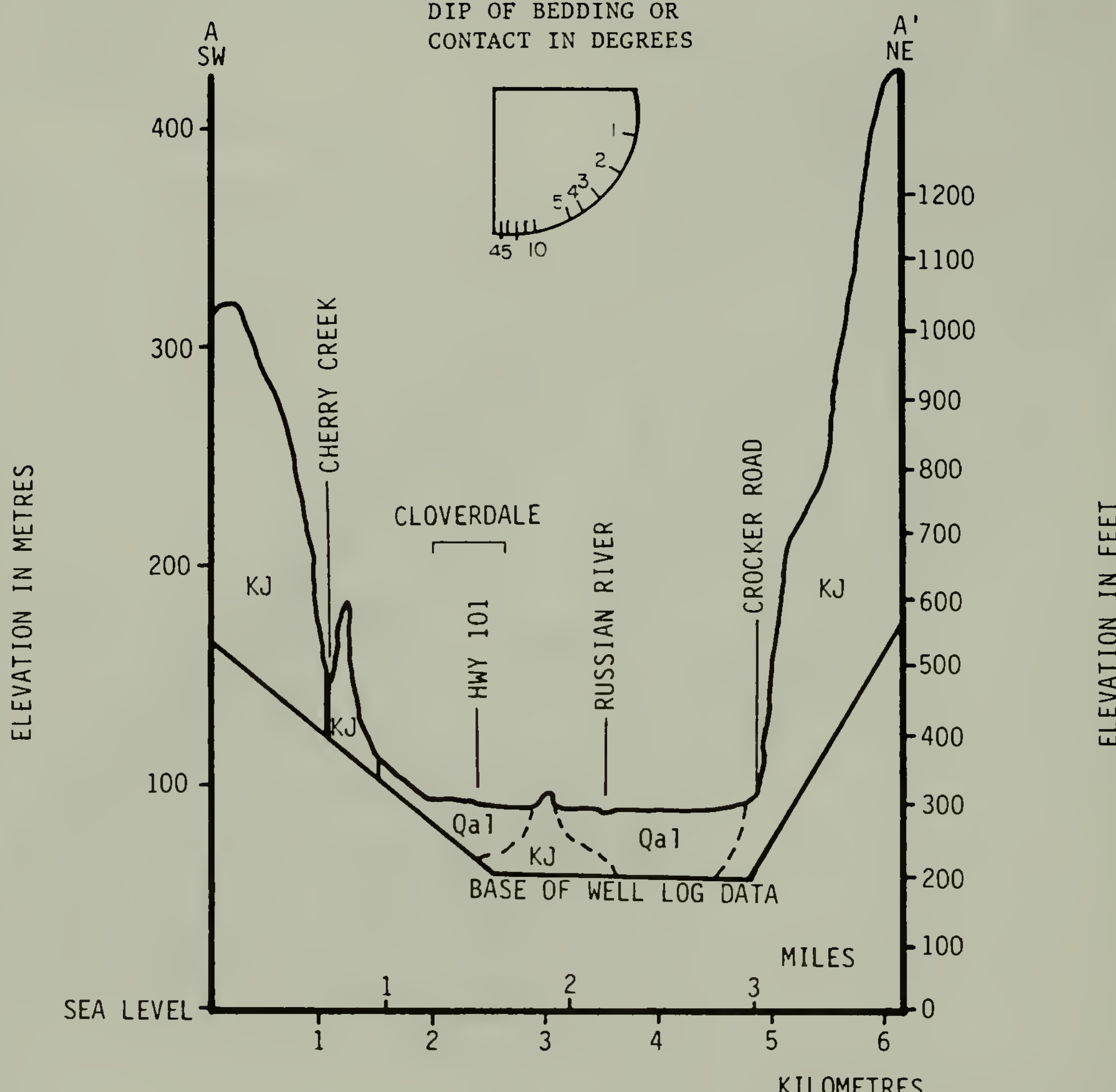
CONTOUR INTERVAL 60 METRES
(200 FEET)

SEE PLATE 1 FOR DETAILED DESCRIPTION OF ROCK UNITS.

KILOMETRES
1 0 1 2 3 4 5

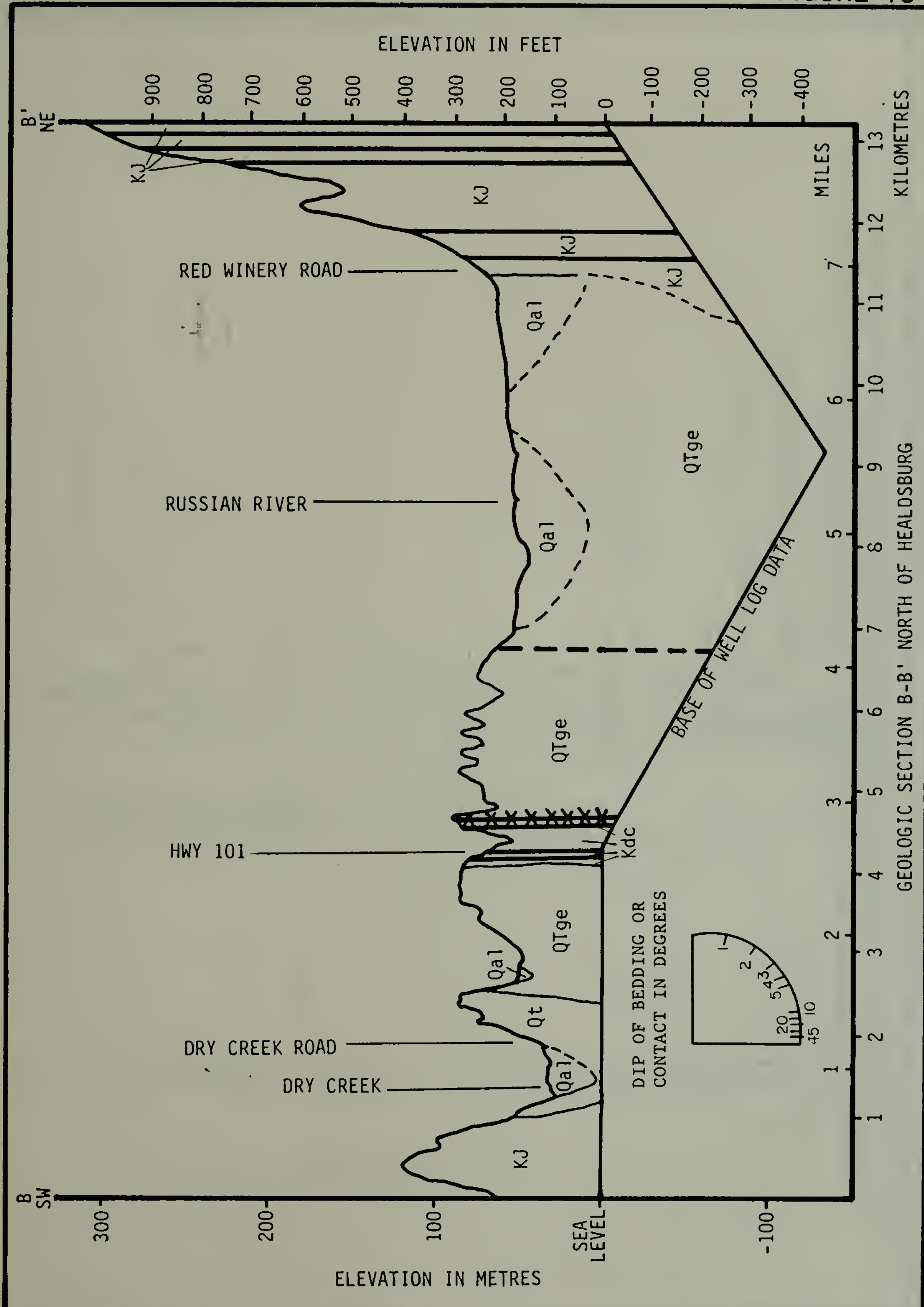
1 0 1 2 3 4
MILES

FIGURE 4B

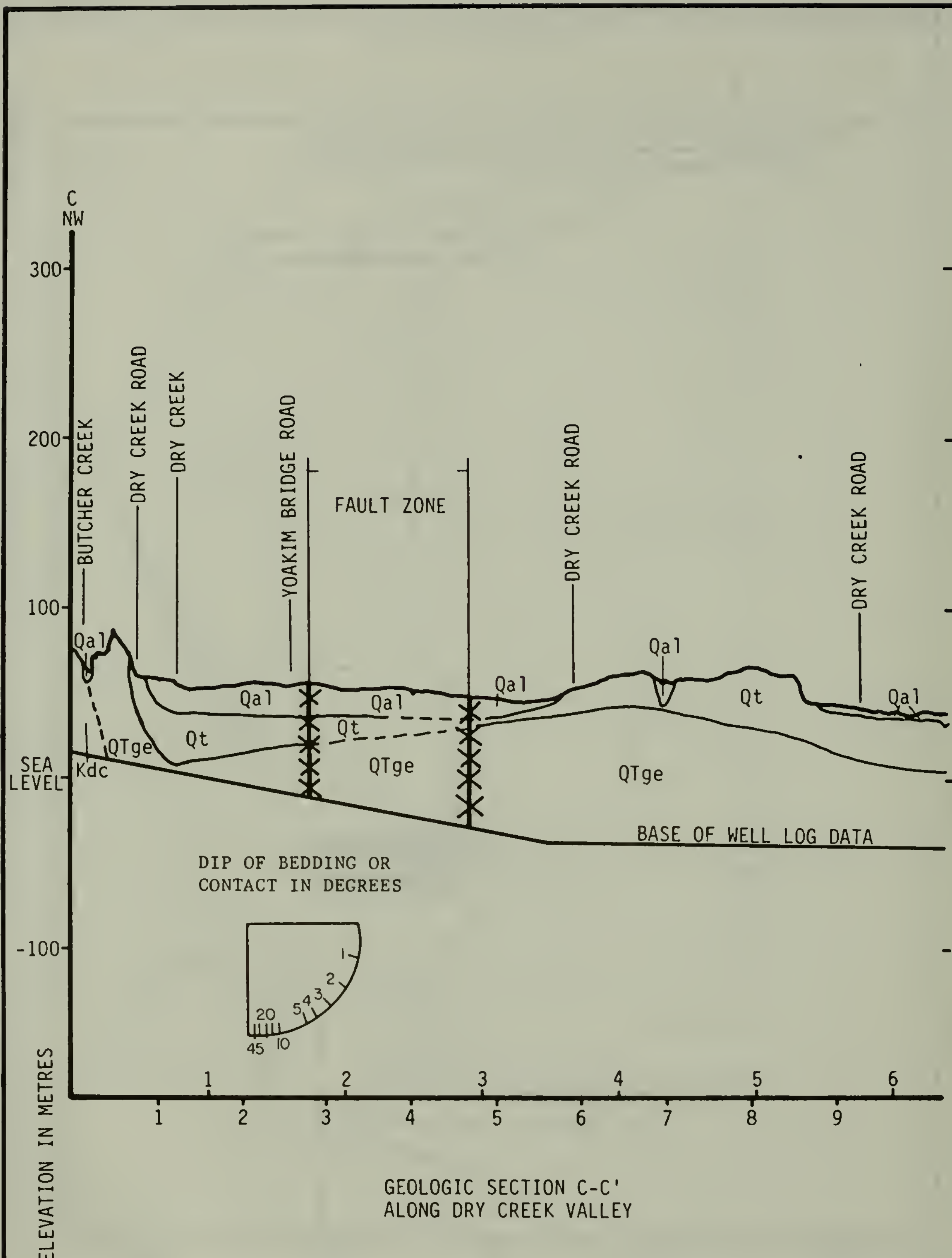


GEOLOGIC SECTION A-A'
THROUGH CLOVERDALE

FIGURE 4C

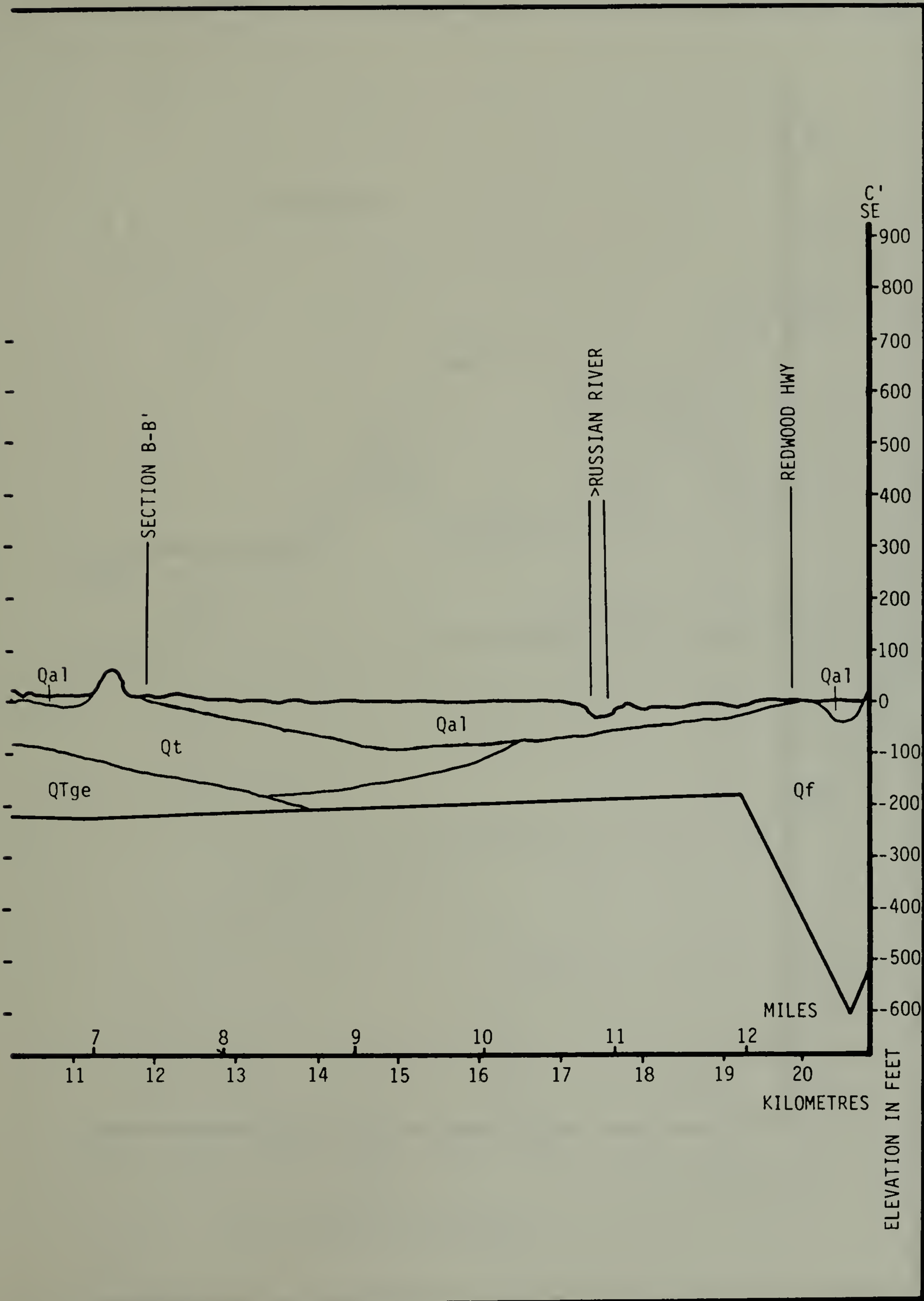


GEOLOGIC SECTION B-B' NORTH OF HEALDSBURG

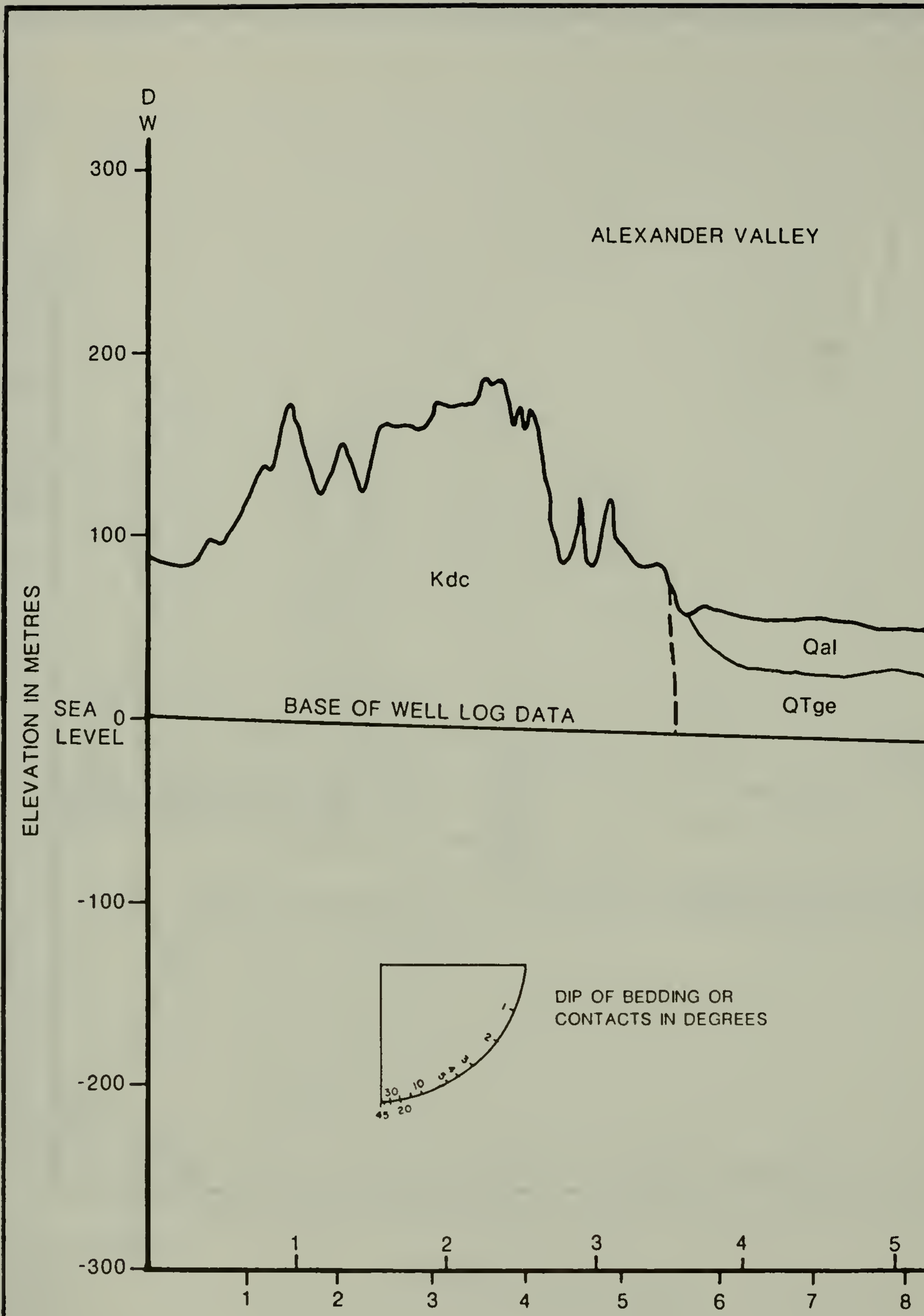


GEOLOGIC SECTION C-C'
ALONG DRY CREEK VALLEY

FIGURE 4D



C'
SE
SECTION B-B'
RUSSIAN RIVER
REDWOOD HWY
Qal
Qal
Qal
Qt
QTge
Qf
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
MILES
7
8
9
10
11
12
11
12
13
14
15
16
17
18
19
20
KILOMETRES
ELEVATION IN FEET



SECTION D-D'
THROUGH ALEXANDER VALLEY

FIGURE 4E

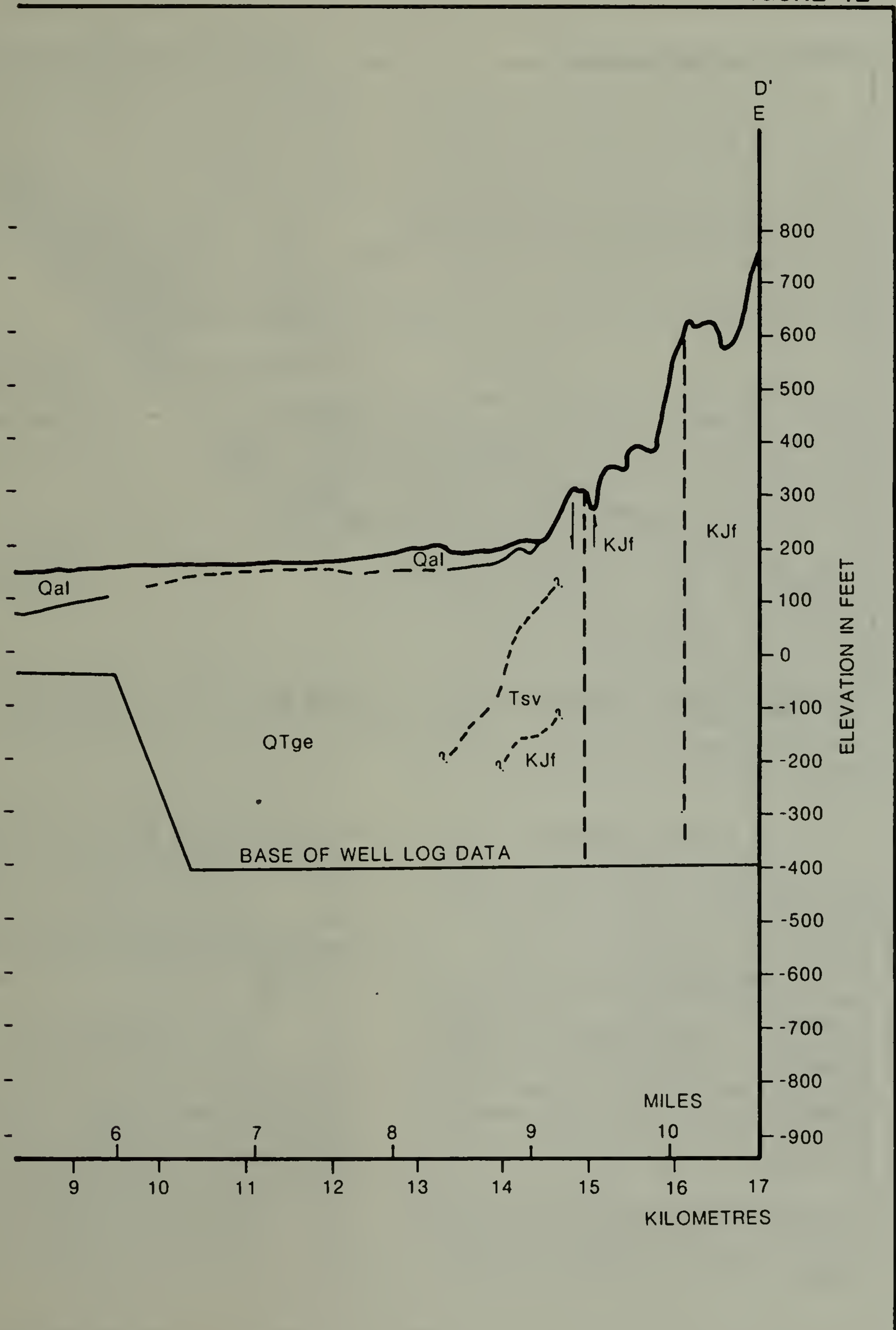


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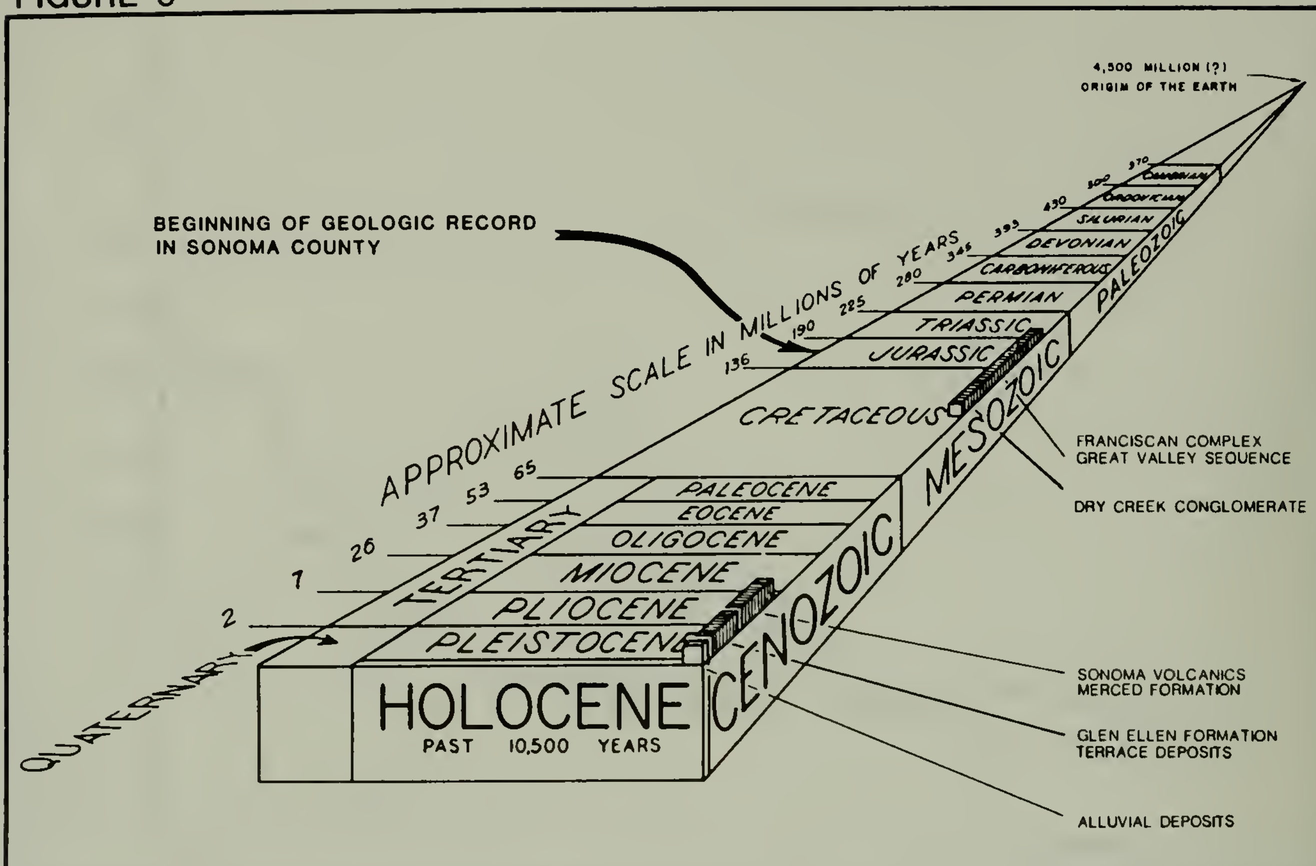
FIGURE 5



LOOKING BACK IN GEOLOGIC TIME—ALEXANDER VALLEY & HEALDSBURG AREA

Sonoma Volcanics

The northernmost extent of the Sonoma Volcanics is in Alexander Valley. The rocks consist principally of basalt flows, tuff, and breccia, but also include andesite, rhyolite, and associated volcanic sediment. The maximum thickness in the vicinity of Alexander Valley and in the Healdsburg area is probably about 300 metres (1,000 feet) (Cardwell, 1965). No data were collected concerning the water-bearing characteristics of these rocks in the study area.

To the south, in Santa Rosa and adjacent valleys, the volcanic rocks yield water to wells, locally in large quantities (Cardwell, 1958). Successful wells that have been drilled into the volcanics generally yield from 40 to 200 litres (10 to 50 gallons) per minute (Ford, 1975). Fractured basalt, flow-contact zones, and coarse-grained volcanic sediments are the water-yielding rocks of the Sonoma Volcanics.

Glen Ellen Formation

The Plio-Pleistocene age Glen Ellen Formation is composed primarily of poorly sorted alluvial fan and flood plain deposits. The sediments include gravel, sand, silt, and clay that have been largely derived from Sonoma Volcanics debris (Cardwell, 1965). Thick units of silty gravel and clay are commonly interbedded with thin lenses of

partially cemented silty sand. The deposits vary widely in extent and thickness, and individual beds rapidly grade into each other, both laterally and vertically. The thickness of the Glen Ellen Formation has been estimated at about 500 metres (1,500 feet) east of the Russian River and along the east side of Dry Creek (Cardwell, 1965). Elsewhere, thickness of the formation is difficult to determine.

The primary outcrops of Glen Ellen are exposed at the southernmost end of Alexander Valley. In the southern half of the valley, drillers' logs of water wells and discontinuous exposures suggest that the Glen Ellen Formation underlies the valley sediments at depths ranging from a few metres to 20 metres (60 feet) below the surface (Cardwell, 1965). The subsurface extent of the Glen Ellen is not well known in the northern half of the valley.

The water-yielding potential of the Glen Ellen Formation varies considerably due to its heterogeneous nature, but permeability is generally low. Most of the wells drilled into the Glen Ellen in the Healdsburg area are for domestic use. The yield from these wells ranges from 5 to 500 litres (1 to 140 gallons) per minute, with a specific capacity of about 25 litres per minute per metre (2 gallons per minute per foot) of drawdown (Cardwell, 1965).

The Glen Ellen Formation exhibits similar water-bearing characteristics in Alexander Valley. Specific capacities of wells are generally low, but high yields may be obtained from wells that penetrate thick sections of the formation. Many wells in the southern part of Alexander Valley produce from the Glen Ellen. Farmers in the southern upland area obtain adequate supplies (450 litres (120 gallons) per minute) of water from the formation at depths of less than 60 metres (200 feet) (Cardwell, 1965).

Terrace Deposits

Remnants of Pleistocene age Terrace Deposits are discontinuously exposed along the Russian River and Dry Creek. They consist of unconsolidated, cross bedded sands, with some silt and clay. The thickness of these deposits varies, but may be up to 61 metres (200 feet) (Ford, 1975). The Terrace Deposits were originally formed as alluvial fan, flood plain, and stream channel deposits, and have since been isolated as the streams have downgraded.

Most terrace deposits may yield adequate supplies of water for domestic, stock, commercial, and limited industrial uses. Wells drilled into these deposits generally yield from 40 to 200 litres (10 to 50 gallons) per minute. Specific capacities range from less than one to about 60 litres per minute per metre (5 gallons per minute per foot) of drawdown (Cardwell, 1965). Higher yields may be obtained where the deposits are fairly extensive and undissected. One well in such material reportedly yielded 1 650 litres (435 gallons) per minute with a drawdown of 30 metres (100 feet). The well is 55 metres (180 feet) deep, and may tap the Glen Ellen Formation beneath the terrace deposits (Cardwell, 1965).

Table 2 shows the variation of some wells within the terrace deposits.

Table 2

WELL YIELDS FROM TERRACE DEPOSITS

Well Number	Yield per Minute Litres	Yield per Minute Gallons	Drawdown Metres	Drawdown Feet
9/9-17R1	75	20	14	44
9/9-22P1	90	24	5	17
8/9-32E3	230	60	16	50
9/10-1G1	800	200	12	38

Alluvium and River Channel Deposits

Unconsolidated alluvium, of Holocene age, underlies the alluvial plains of the Russian River, Dry Creek, and tributary streams. Those deposits adjacent to the river and streams consist of loose, permeable gravel and sand that range in thickness from a few metres to more than 24 metres (80 feet) (Cardwell, 1965). Farther from the river, the alluvium contains less coarse-grained material and more silt and poorly sorted sand and gravel deposited by tributary creeks. As a result, the alluvium away from the river is less permeable than alluvium near the river, and yields less water to wells.

In general, high yields are possible from wells that produce from the alluvium, and this source supplies most of the ground water used in the Healdsburg area. Near the river, wells 8 to 15 metres (25 to 50 feet) deep generally yield 800 to 2 000 litres (200 to 500 gallons) per minute (Cardwell, 1965). In the marginal areas, where little river channel gravel exists, wells have a lower yield. It is possible for wells in the alluvial deposits to yield 3 800 litres (1,000 gallons) or more, provided the wells are correctly located and properly constructed (Cardwell, 1965).

Many irrigation wells in both valleys obtain their water supply from the alluvium, but yields greater than 2 000 litres (500 gallons) per minute are not generally required because the amount of land irrigated by individual wells is relatively small. The specific capacities of irrigation wells drilled into the alluvium commonly range from 200 to 800 litres (50 to 200 gallons) per minute (Cardwell, 1965).

The term geohydrology refers to the study of flow characteristics of subsurface waters; the term is synonymous with ground water hydrology (see Figure 6). Geohydrology includes such topics as the occurrence, movement, and recharge of ground water, each of which is discussed below. Also included in this chapter are discussions of related topics such as water level fluctuations, ground water storage capacity, computer-assisted geologic evaluations, and identification of the ground water basin and sub-basin boundaries.

Ground Water Basin

A ground water basin is an area underlain by permeable materials capable of furnishing a significant supply of ground water to wells. A basin is 3-dimensional and includes both the surface extent and all of its subsurface materials that yield fresh water. Ground water basins usually can be divided into a valley floor area and upland ground water terrain. The valley floor area normally constitutes the major part of a ground water basin, and it is usually an area of low to negligible relief. Ground water basins in California are formally defined by Peters (1980). The study area for this report consists only of the Alexander Valley, Cloverdale Valley, and Healdsburg area portions of Sonoma County Basin. The area studied is further restricted to the water-bearing deposits in those sub-basins.

Geologic features such as impermeable bedrock, smaller cross-sectional areas of alluvial material, folded sedimentary rocks, and faulted rocks can all affect the movement of ground water within and between sub-basins (see Figure 7). If the flow of ground water is sufficiently reduced, such geologic features may even be considered to be basin boundaries.

Impermeable bedrock includes rocks that either yield no water at all or that yield water so slowly that they are suitable only for a domestic supply or for a water system that has extensive storage facilities and a low rate of use. In Alexander Valley and the Healdsburg area, the Franciscan Complex is essentially impermeable bedrock.

The canyon that connects Alexander Valley and the Healdsburg area has been eroded in the Franciscan Complex, a relatively impermeable bedrock, by the Russian River. The canyon contains only a minor amount of water-bearing stream channel deposits.

A similar reduced section of water-bearing materials occurs between Cloverdale Valley and Alexander Valley near Asti. This constriction is shorter and wider than that between Alexander Valley and the Healdsburg area, but nevertheless it also constitutes a ground water boundary between two sub-basins.

Faults are fractures in the rock along which the rocks on either side have been moved. The fracture might or might not intersect the earth's surface. Faults sometimes create zones of crushed and broken rock along the fault trace. This crushed material can be clay-rich, impeding the movement of ground water across the fault and thus acting as a barrier.

Although there are many faults in the uplands that separate Alexander Valley from the Healdsburg area, as well as in the surrounding foothills, the fault in Dry Creek Valley is the only one mapped as cutting the alluvium and stream channel deposits. So few measurements of water levels in wells are available that it is not known whether this Dry Creek Valley fault acts as a barrier to the movement of ground water.

FIGURE 6

GROUND WATER TERMINOLOGY

The science of ground water hydrology deals with the distribution and behavior of ground water -- how much water is contained in any geologic material and how easily it can be extracted. The science of ground water geology deals with the effect of geology on the distribution and movement of ground water -- how different geologic materials and geologic structures determine the rate and paths of movement of ground water. By knowing the geology of an area, the subsurface hydraulic properties of that area can be estimated, because ground water hydrology and ground water geology are closely related.

Geologic formations can be divided into two groups: water-yielding and nonwater-yielding. Water-yielding formations, which usually consist of unconsolidated deposits of sand and gravel, readily absorb, transmit, and yield large quantities of ground water to wells. Nonwater-yielding formations, which usually consist of clay and consolidated rocks, yield only limited quantities of water to wells. Each geologic formation has specific hydraulic properties: porosity, permeability, specific yield, and transmissivity.

POROSITY AND PERMEABILITY

Porosity is the ratio of the volume of the voids between the particles in a sample to the total volume of the sample.

$$\text{Porosity} = \frac{\text{volume of voids}}{\text{total volume of sample}} (100) = \%$$

Porosity is not necessarily indicative of permeability, which indicates the ease with which ground water moves through a material. If the openings between the particles are small or are not connected, the permeability of the material is low. For example, clay contains a large number of small voids, so its porosity may be as high as 50 percent. Because of the physical and chemical nature of clay, it transmits very little water and it has a very low permeability, about 1.07×10^{-4} metres (3.5×10^{-4} feet) per day.* The porosity of sand and gravel is about 20 percent, much lower than the porosity of clay, but the voids in the sand and gravel are larger and are interconnected. Thus, most sands and gravels transmit water readily, having a permeability of about 1.07×10^{2} metres (3.5×10^{2} feet) per day.

A permeable geologic unit is called an aquifer. A relatively impermeable geologic unit is called an aquiclude or an aquitard because it retards the flow of water; both are called confining beds because they block the movement of ground water. Confining beds usually consist of clay or other fine-grained sediments. They contain ground water but have low permeability and cannot transmit extractable quantities. Granite is an example of an aquifuge because ground water cannot flow through it; granite is neither porous nor permeable. Ground water does flow through joints in the granite, but that geologic complication is a result of structural complexities not related to porosity or permeability. The porosity and permeability of formations composed of clay, sands, and gravels generally decrease through time as the formation becomes more consolidated.

SPECIFIC YIELD

Specific yield is the ratio of the volume of water that will drain due to gravity from a saturated sample of material to the total volume of the sample.

$$\text{Specific Yield} = \frac{\text{volume of water drained}}{\text{total volume of sample}} (100) = \%$$

The higher the specific yield of a geologic unit, the more water it will yield. Listed below are representative specific yield values for common geologic materials. Geologic materials having a more uniform grain size distribution will have a greater specific yield because of the greater total amount of space between particles. Consolidated rock and rocks such as basalt and granite are given specific yield values close to zero because water is contained only in fractures and not within the rock. The volume of water stored in fractured rock is highly variable, depending on the size and extent of the fractures, and cannot be easily quantified.

% Specific Yield	3	5	10	20	25
Geologic Material	Adobe Clay Shale	Cemented Gravel Cemented Sand Clay and Gravel Silt	Clay, Sand, & Gravel Fine Sand Quicksand Sand and Clay	Coarse Sand Loose Sand Medium Sand	Gravel Sand and Gravel

TRANSMISSIVITY

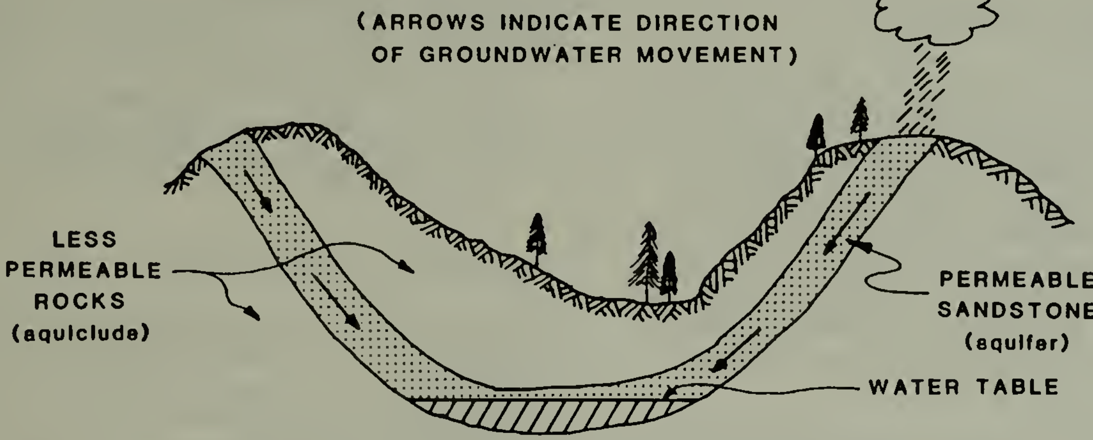
Transmissivity is the rate at which ground water will flow through a unit width of an aquifer, and is equal to the permeability of an aquifer multiplied by its thickness. The transmissivity of an aquifer or formation can generally be determined only from water level data collected during extended pumping of a water well. During a constant-rate pump test, abrupt changes in the slope of the curve from which transmissivity is determined indicate either the presence of a barrier, which impedes ground water movement, or the presence of a source of ground water recharge.

*"Metres per day" and "feet per day" are standard velocity units that indicate the amount of ground water that moves through a given cross-sectional area in one day:
a. 1 cubic metre of ground water moves through 1 square metre in 1 day. The units are: $1\ m^3 / m^2 / \text{day} = 1\ \text{m/day}$
b. 1 cubic foot of ground water moves through 1 square foot in 1 day. The units are: $1\ ft^3 / ft^2 / \text{day} = 1\ \text{ft/day}$

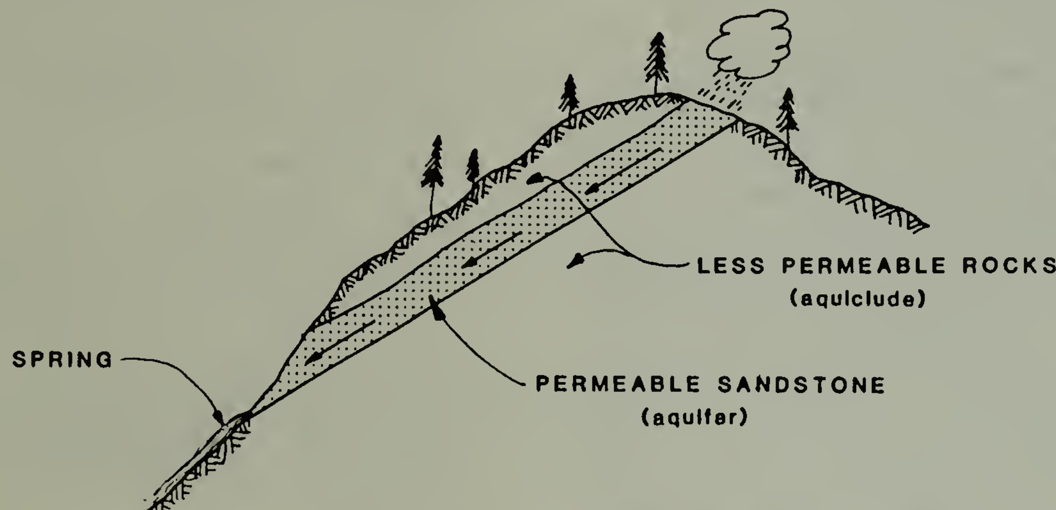
FIGURE 7

MOVEMENT OF GROUND WATER

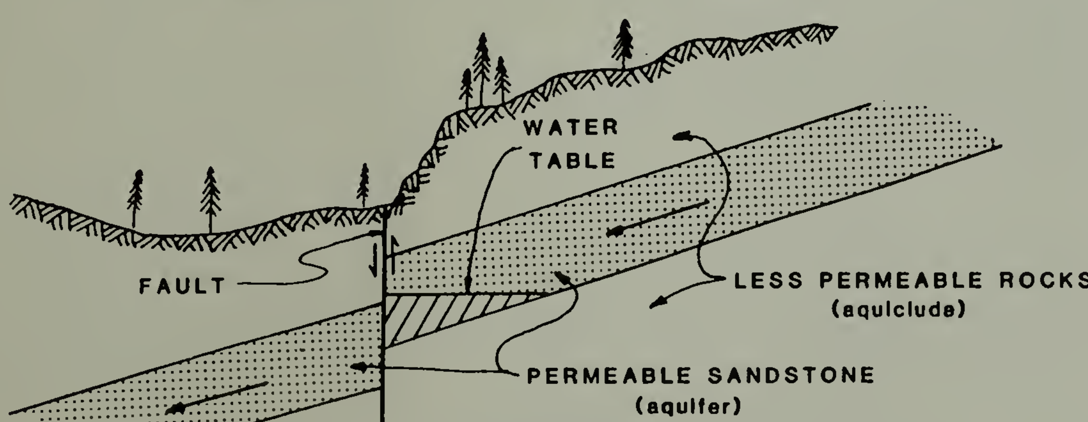
(ARROWS INDICATE DIRECTION OF GROUNDWATER MOVEMENT)



GROUND WATER MOVES DOWNDIP
UNTIL IT REACHES THE LOWEST POINT IN ELEVATION



GROUND WATER MOVES DOWNDIP UNTIL
THE PERMEABLE ROCKS ARE AGAIN AT THE SURFACE
GROUND WATER IS RELEASED AS A SPRING



TRANSMISSIVITY IS REDUCED ACROSS FAULT
GROUND WATER "STACKS UP" ON UPHILL SIDE OF FAULT

Ground Water Occurrence and Movement

Ground water in the Alexander Valley and Healdsburg area occurs in the alluvial materials and river channel deposits, with some water coming from the Glen Ellen Formation. Older rocks, such as those belonging to the Franciscan Complex and Dry Creek Conglomerate, are tapped in and near the foothills and yield only minor quantities of water to wells.

In Alexander Valley, ground water moves from the margins toward the Russian River during most of the year. When ground water levels are depressed, usually during the fall, flow in Russian River recharges the ground water reservoir. The distance from the river that such recharge occurs is not known. Local movement of river water into the alluvium occurs during high river stages in the autumn and winter, and also in summer in areas where large withdrawals are made close to the river (Cardwell, 1965). Most recharge to the ground water is derived from infiltration of rain that falls on the valley floor and from seepage into permeable deposits that underlie channels of the tributary streams. The gravelly alluvial cone of Big Sulphur Creek is a large source of recharge both from infiltrating rain and from streamflow.

Large quantities of subsurface flow are contained in the channel deposits of the streams. Dry Creek subsurface flow into the Healdsburg subunit has been estimated at 1 230 cubic dekametres (1,000 acre-feet) per year (Finlayson, 1980).

Occurrence, movement, and fluctuation of ground water are determined through analysis of water level data obtained from a number of wells located throughout a ground water basin. These data provide an insight to the ground water conditions within the area under study. Most of these water level data are of a composite nature, because they do not represent actual potentiometric conditions for any specific aquifer or water-bearing stratum, but represent an average for all water-bearing strata intercepted by a particular well.

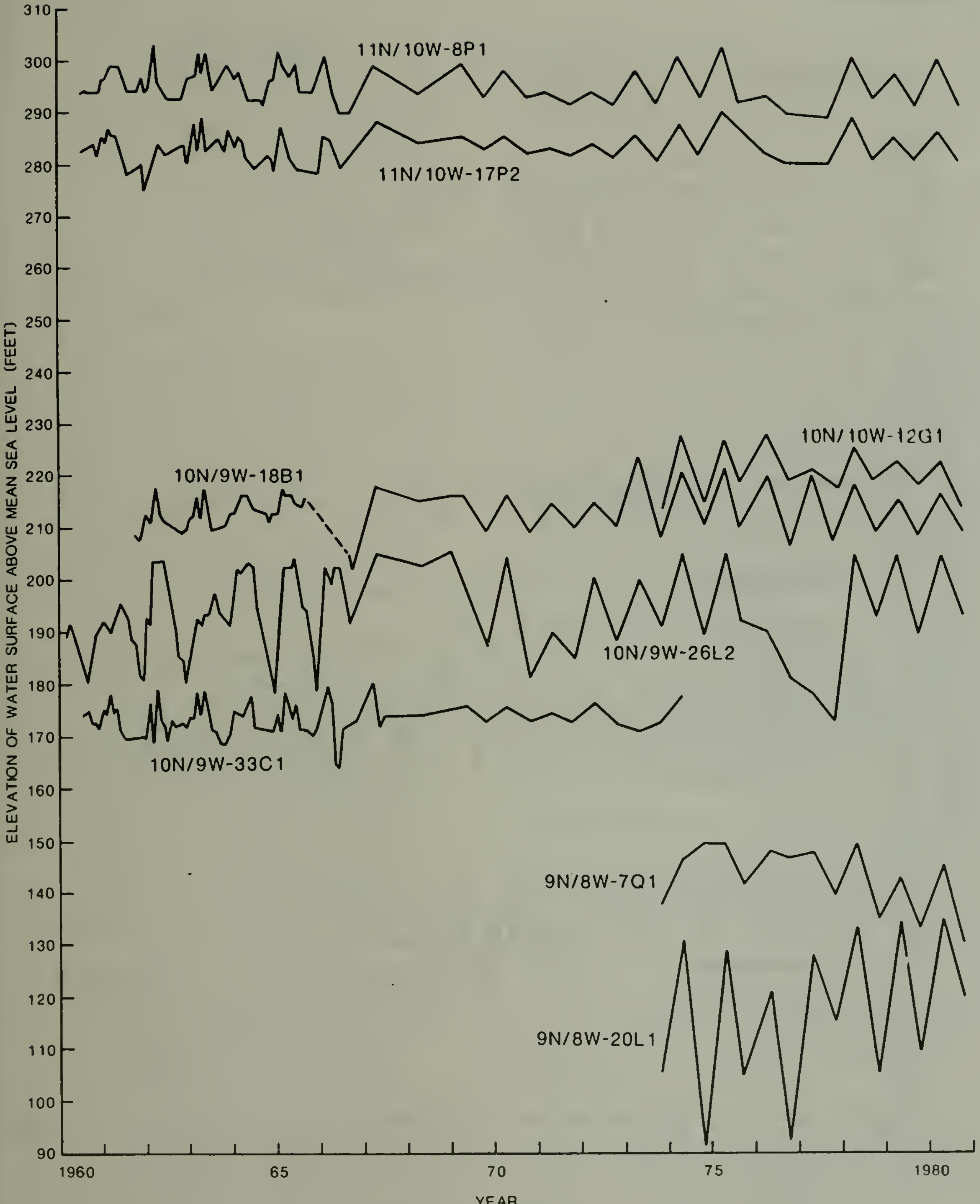
Water Level Fluctuations

Typical water level fluctuations in the study area are shown on ground water hydrographs in Figures 8A and 8B. A hydrograph is a graphical record of water level measurements that have been taken over a period of time. The spring water level reading represents the highest level to which the ground water has recovered after winter precipitation. Conversely, the fall measurement represents the lowest cyclic level to which the ground water has dropped after summer pumping.

Long-term hydrographs reveal any changes in the water levels of various ground water bodies. Data of this type are available from 17 key wells -- 9 in Alexander Valley and 8 in the Healdsburg area (see Figures 8A and 8B). Some of these wells have been measured since 1960, giving a good indication of the nature of the ground water units that the wells tap.

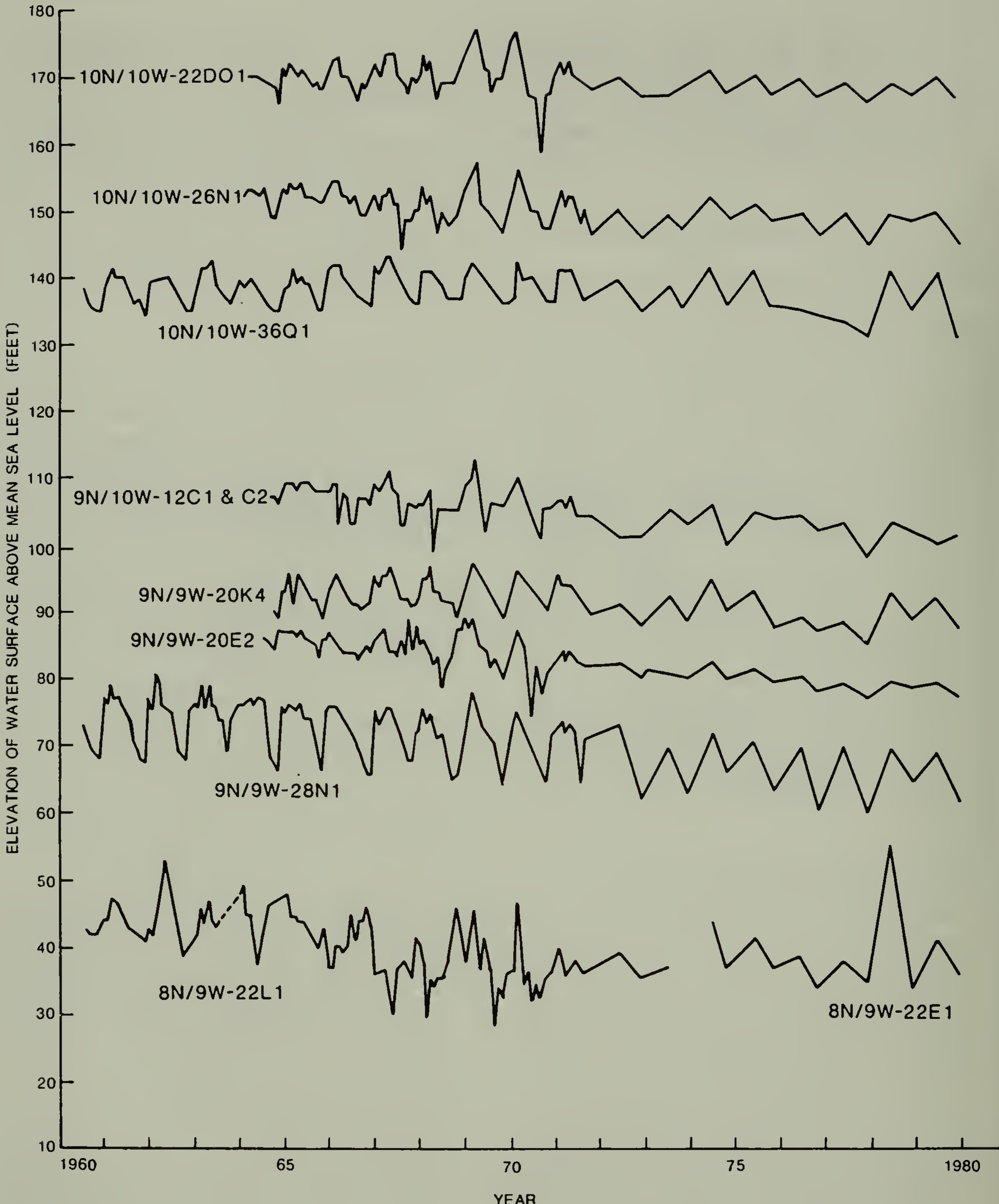
The hydrographs in the study area indicate essentially no long-term change in water levels over a 20-year period. This suggests that the aquifer systems tapped by most of these wells are being adequately recharged to meet the seasonal demands on ground water and that no long-term overdraft exists. The range of fluctuations in wells in the alluvial plain is less than 3 metres (10 feet) per year, suggesting that water levels are affected only by natural recharge, discharge, pumping, and variations in rainfall. Seasonal fluctuations in the upland areas and near the margin of the alluvial plain are generally somewhat greater.

FIGURE 8A



WELL HYDROGRAPHS
ALEXANDER VALLEY

FIGURE 8B



WELL HYDROGRAPHS
HEALDSBURG AREA

Computer-Assisted Geologic Evaluation

One of the goals of this study was to determine the total volume of ground water in storage and the available ground water storage capacity. Available storage capacity indicates the capability of the cell to store additional ground water from natural or artificial recharge. This was determined with the aid of the computer program TRANSCAP.

The input to TRANSCAP was based on drillers' logs of water wells. All well logs in the study area were located and assigned to the proper cell area. Each cell is equivalent to a section or half section -- 260 or 130 hectares (640 or 320 acres). Figure 11 (page 34) shows the cell boundaries. The study area was divided into 95 cells. Cells 1 to 56 are in Alexander Valley, and cells 57 to 95 are in the Healdsburg area.

Each well log was analyzed, and the descriptions of subsurface materials encountered in each well were translated into Equivalent Specific Yield (ESY) values. ESY was defined by Ford and Finlayson (1974) as a property of the geologic material numerically equal to the specific yield, but without the connotation of the quantity of ground water contained therein.

ESY data were then used as input for TRANSCAP for all selected wells in the ground water basin.

TRANSCAP was not run for those cells with surficial geology composed mainly of the Franciscan Complex and the Dry Creek Conglomerates because those geologic units yield little water.

The TRANSCAP program adjusts all wells within a cell to the average elevation of the land surface in that cell. The program then averages all the ESY data from all wells in that cell for each 3-metre (10-foot) increment of depth. The averaged data are related to permeability using a curve developed during the Department of Water Resources investigation of the Livermore and Sunol Valleys (Ford and Hills, 1974). Permeability is then converted to transmissivity using the estimated water-bearing thickness. When no drillers' logs were available for a cell, storage capacity values were extrapolated from another cell with similar geology.

A sample TRANSCAP printout (in customary units) is shown on Figure 9. The variables listed in the upper left-hand corner of the table describe the values used to set up TRANSCAP for this cell (Node 7). Increment of Depth = 10 indicates that specific yields are averaged over 3-metre (10 foot) intervals. Node Elevation Control is the average elevation of the land surface within the cell. Node Surface Area is the surface area (in acres) of the cell or part of a cell. Note that the center point in a cell is called the "node".

In the table, intervals are described in terms of both "depth" below land surfaces and "elevation" relative to sea level. For example, for the interval between 3 to 6 metres (10 to 20 feet) above sea level, at a depth of 67 to 70 metres (220 to 230 feet):

° Average specific yield is 15 percent.

° Unit width transmissivity is 38 000 litres (10,000 gallons) per day.

° Storage capacity is 8 900 cubic dekametres (7,200 acre-feet).

The computer-generated numbers should be rounded before use to one or two significant figures to avoid the impression of precision.

To determine the ground water storage capacity of any cell, the bottom of the water-yielding zone must first be established. The graph on Figure 9 shows a profile of the transmissivity in the sample cell. The more horizontal the line, the better the water-yielding

FIGURE 9

NODE 7

SONOMA COUNTY
GROUND WATER INVESTIGATION
DEPTH INCREMENT CALCULATIONS FROM SPECIFIC YIELD

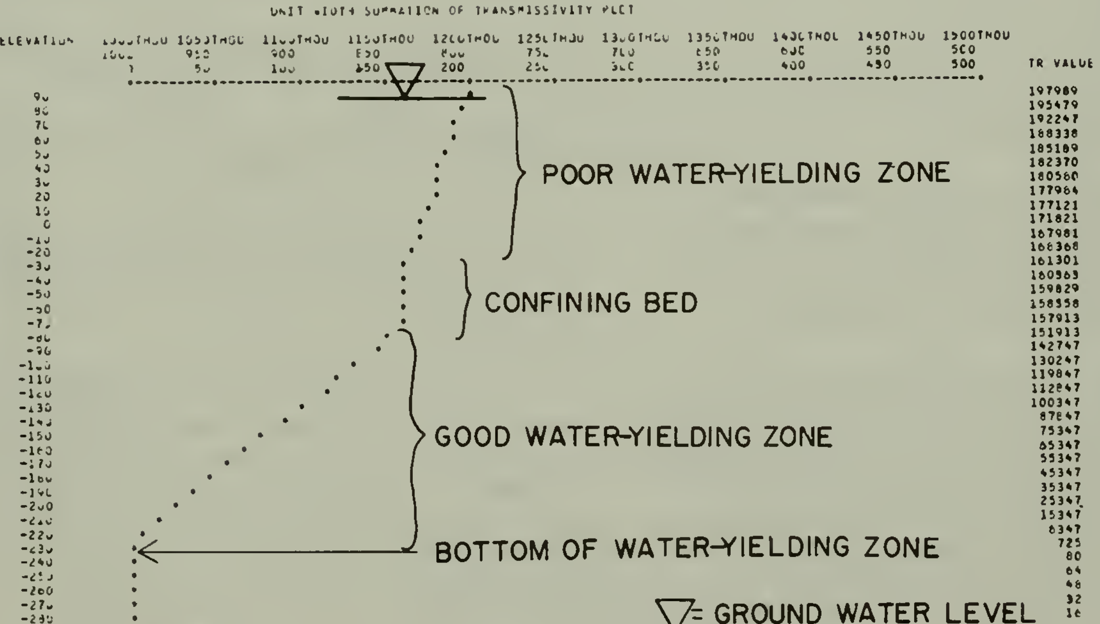
PAGE 3
DATE 10/27/81

INCREMENT OF DEPTH = 10
NODE ELEVATION CONTROL = 100
NODE SURFACE AREA (ACRES) = 654

SY VALUE FOR CLAY = 3

DEPTH	ELEVATION	AVERAGE SPECIFIC YIELD (IN PERCENT)	UNIT WIDTH TRANSMISSIVITY (GAL/DAY)	UNIT WIDTH TR FOR USE IN MODEL AC-FT/YR	STORAGE CAPACITY (ACRE-FEET)	STORAGE CAPACITY TO BOTTOM (ACRE-FEET)	NO. OF SAMPLES
10	90	7.17	2540	221	466	24178	12
20	80	7.85	3232	219	513	88 23710	13
30	70	6.46	3505	215	553	23197	13
40	60	7.77	3149	211	508	22644	13
50	50	7.46	2619	207	487	22136	13
60	40	6.46	1820	204	422	21649	13
70	30	7.25	2598	202	474	21227	12
80	20	5.30	843	199	346	20753	10
90	$\boxed{10}$	$\boxed{10.30}$	$\boxed{5300}$	198	$\boxed{673}$	20407	10
100	0	8.40	3540	192	549	19734	10
110	-10	6.25	1613	168	406	19185	8
120	-20	9.50	5067	186	621	16777	8
130	-30	5.14	736	180	336	16156	7
140	-40	5.14	736	179	336	17820	7
150	-50	5.86	1271	179	383	17484	7
160	-60	5.00	645	177	327	17102	6
170	-70	11.00	6600	177	719	16774	6
180	-80	14.17	9166	170	926	16055	6
190	-90	17.50	12500	160	1144	15129	6
200	-100	15.40	10400	146	1007	13965	5
210	-110	12.00	7000	134	784	12978	4
220	-120	17.50	12500	126	1144	12194	2
230	-130	17.50	12500	112	1144	11050	2
240	-140	17.50	12500	96	1144	9906	2
250	-150	15.00	10000	84	981	8762	1
250	-160	15.00	10000	73	981	7781	1
270	-170	15.00	10000	62	981	6800	1
280	-180	15.00	10000	50	981	5819	1
290	-190	15.00	10000	39	981	4838	1
300	-200	15.00	10000	28	981	3857	1
310	-210	14.00	9000	17	915	2876	1
320	-220	10.00	5522	7	654	1961	1
330	-230	5.00	645	0	327	1307	1
340	-240	3.00	16	0	196	980	1
350	-250	3.00	16	0	196	784	1
360	-260	3.00	16	0	196	588	1
370	-270	3.00	16	0	196	392	1
380	-280	3.00	16	0	196	196	1

UNIT WIDTH SUMMATION OF TRANSMISSIVITY PLOT



SAMPLE TRANSCAP PRINTOUT

zone. The more vertical the line, the more that zone functions as a confining bed. The bottom of the water-yielding zone is determined from the TRANSCAP graph and is verified by comparison with geologic maps and cross sections. The top of the water-yielding zone is generally assumed to be the land surface.

The net storage capacity of the water-yielding zone is calculated by subtracting the storage capacity to bottom figure at the bottom of the water-yielding zone from the corresponding figure at the top of the water-yielding zone. A typical work sheet is shown on Table 3.

Table 3

SUMMARY OF ALEXANDER VALLEY AND HEALDSBURG NODAL STORAGE

Node	Surface Area (Acres)	Top of Aquifer Elevation (Feet)	Bottom of Aquifer Elevation (Feet)	Total Storage Capacity (Acre-Feet)	Fall of 1980 Ground Water Elevation (Feet)	Fall of 1980 Saturated Storage Space (Acre-Feet)	Fall of 1980 Dewatered Storage Space (Acre-Feet)
1	160	320	260	1,100	300	887	213
2	320	320	180	4,470	290	3,318	1,152
3	160	320	260	1,100	310	887	213
4	480	320	210	5,728	300	4,816	912
5	320	300	190	5,088	300	5,088	0
6	640	320	230	4,089	310	2,489	1,600
7	640	290	190	13,044	290	13,044	0
8	480	330	210	2,448	320	1,944	504
9	240	310	190	5,484	280	4,512	972
10	480	320	200	6,349	290	5,917	432
11	480	270	190	2,208	270	2,208	0
12	640	360	200	10,679	270	5,117	5,562
13	640	290	200	9,002	260	4,394	4,608
14	640	330	230	4,000	240	256	3,744
15	320	250	80	6,304	225	4,784	1,520
16	480	230	100	12,048	210	11,088	960
17	640	220	60	24,106	200	21,060	3,046
18	320	220	50	4,840	195	3,946	894
19	640	210	30	21,818	195	19,838	1,980
20	320	230	-120	10,280	200	9,463	817
21	160	210	60	5,616	190	4,816	800
22	640	190	30	20,115	180	18,793	1,322
23	320	190	50	10,240	175	9,424	816
24	160	290	160	1,395	210	599	796
25	320	200	90	5,632	170	4,936	696
26	640	180	50	18,387	170	17,043	1,344
27	480	180	-50	16,719	180	16,719	0
28	640	210	-50	17,189	190	15,717	1,472
29	160	220	-90	5,330	195	4,710	620
30	320	180	50	7,488	155	6,992	496
31	640	170	-60	21,645	160	21,364	281
32	640	170	-140	33,220	160	32,666	554
33	640	180	-70	16,590	170	16,270	320
34	640	210	-100	18,372	180	17,220	1,152
35	640	230	-90	22,040	170	19,355	2,685

Table 3 (Continued)

Node	Surface Area (Acres)	Top of Aquifer Elevation (Feet)	Bottom of Aquifer Elevation (Feet)	Total Storage Capacity (Acre-Feet)	Fall of 1980 Ground Water Elevation (Feet)	Fall of 1980 Saturated Storage Space (Acre-Feet)	Fall of 1980 Dewatered Storage Space (Acre-Feet)
36	320	220	110	4,091	160	2,687	1,404
37	480	200	-150	22,010	155	19,156	2,854
38	640	170	-180	14,740	160	14,108	632
39	480	220	-40	9,051	150	6,507	2,544
40	160	300	0	22,040	170	19,355	2,685
41	320	320	120	4,091	170	3,241	850
42	160	170	120	539	140	212	327
43	640	180	-330	38,490	135	35,200	3,290
44	480	220	-40	9,051	140	6,267	2,784
45	320	170	120	539	135	130	409
46	640	180	-330	38,490	140	35,472	3,018
47	320	400	-330	55,386	145	35,813	19,573
48	160	160	100	1,728	130	864	864
49	640	190	-20	11,582	140	9,841	1,741
50	640	280	-30	18,656	150	10,144	8,512
51	640	320	-100	18,548	135	6,356	12,192
52	640	370	-280	34,496	145	14,560	19,936
53	480	540	-300	66,138	150	36,154	29,984
54	640	400	130	12,224	150	640	11,584
55	640	610	140	9,024	155	6,240	2,784
56	320	930	-100	67,348	160	6,548	60,800
57	160	210	90	2,335	185	2,015	320
58	160	210	90	2,335	180	1,951	384
59	480	190	-60	15,691	175	15,043	648
60	160	190	110	1,850	170	1,466	384
61	480	180	100	4,078	165	3,402	676
62	320	170	-100	7,461	160	7,289	172
63	480	200	-80	15,217	150	12,625	2,592
64	640	170	-70	12,163	140	10,562	1,601
65	480	240	-80	17,904	130	12,192	5,712
66	320	150	30	3,737	125	3,189	548
67	640	170	-30	14,526	110	10,900	3,626
68	640	220	50	8,009	100	2,510	5,499
69	160	240	-40	3,814	95	1,841	1,973
70	160	120	60	1,028	95	630	398
71	640	170	-100	16,588	95	12,445	4,143
72	640	210	10	11,320	95	5,064	6,256
73	320	110	-240	18,610	85	17,823	787
74	640	170	0	9,645	85	6,455	3,190
75	320	150	-40	7,536	85	3,480	4,056
76	640	90	-20	7,066	75	6,404	662
77	640	110	20	9,074	75	5,701	3,373
78	160	100	70	240	75	40	200
79	480	90	-150	17,144	70	16,212	932
80	640	90	-40	9,443	70	8,643	800
81	640	110	-40	7,754	70	6,340	1,414
82	320	90	10	2,192	60	1,728	464
83	640	80	-10	9,254	55	7,167	2,087
84	640	110	-60	11,351	60	8,203	3,148
85	640	250	140	4,602	180	2,085	2,517
86	480	400	180	9,456	200	1,872	7,584
87	640	80	-80	5,618	45	4,050	1,568
88	640	100	-420	50,996	50	47,232	3,764
89	320	150	20	3,274	55	880	2,394
90	640	80	-200	22,709	40	18,752	3,957
91	640	130	-300	37,022	40	30,592	6,430
92	640	80	-200	31,696	35	26,431	5,265
93	640	130	-300	28,144	35	22,805	5,339
94	480	60	-200	18,544	35	17,160	1,384
95	640	120	-300	29,125	35	26,337	2,788

To determine the volume of water in storage, the average ground water level for the cell is determined from a ground water level map. The volume of water in storage is determined by subtracting the storage capacity to bottom figure at the bottom of the water-yielding zone from the corresponding figure at the ground water table elevation. This method assumes that all ground water in the area studied is unconfined.

Water level information for fall 1980 (Figure 10) was combined with the product of TRANSCAP to determine the storage capacity, the total volume of water in storage, and the available ground water storage capacity. Available storage capacity indicates that the cell may be able to store additional ground water from natural or artificial recharge. The available storage capacity of each cell is shown on Figure 11.

Total Water in Storage

The total ground water storage capacity, total volume of water in storage, and the available ground water storage capacity are given in Table 4. There were not enough ground water level data before fall 1980 to construct ground water level maps, but hydrographs of wells monitored in the past were examined for trends. The hydrographs indicate that ground water levels within the study area have generally remained constant. Even the drought of 1976 and 1977 did not seem to have affected water levels in any appreciable way. In general, therefore, the volume of ground water stored in Alexander Valley and the Healdsburg area has not changed.

Experience has shown that not all of the ground water in storage can be extracted, nor can all of the unsaturated available storage space be used. Sustained yield is the volume of ground water that can be extracted annually without adversely affecting the ground water basin. Sustained yield generally equals annual recharge to the basin, but the yield can be increased over a short time to temporarily remove an additional volume of water beyond normal seasonal fluctuations. Such withdrawal produces additional storage space for the recharge of surplus surface water during wet years. As with any lithologically heterogeneous ground water basin, substantial and sustained lowering of piezometric levels in confined aquifer systems may result in subsidence.

To determine the recharge rate, and therefore the sustained yield of the basin, certain data are required that are not available in Alexander Valley and the Healdsburg area. The data needed are:

- The volume of water removed from the ground water basin, which includes:
  - Volume of municipal and private ground water pumpage.
  - Volume of surface water flow into and out of the study area.
  - Volume of water used by vegetation (evapotranspiration).
  - Volume of water used for irrigation and frost control.
- The volume of water returned to the ground water basin from all sources, including:
  - Precipitation.
  - Irrigation.
  - Frost control.
  - Artificial recharge.
  - Streamflow.
  - Subsurface sewage disposal systems.

In summary, only the volume of annual change in ground water storage in Alexander Valley and the Healdsburg area has been estimated using information from TRANSCAP.

The change in storage estimate was based on uniform ground water level fluctuations of 3 metres (10 feet) between spring and fall each year in all cells. Hydrographs of wells being monitored show that the water level generally fluctuates within that range.

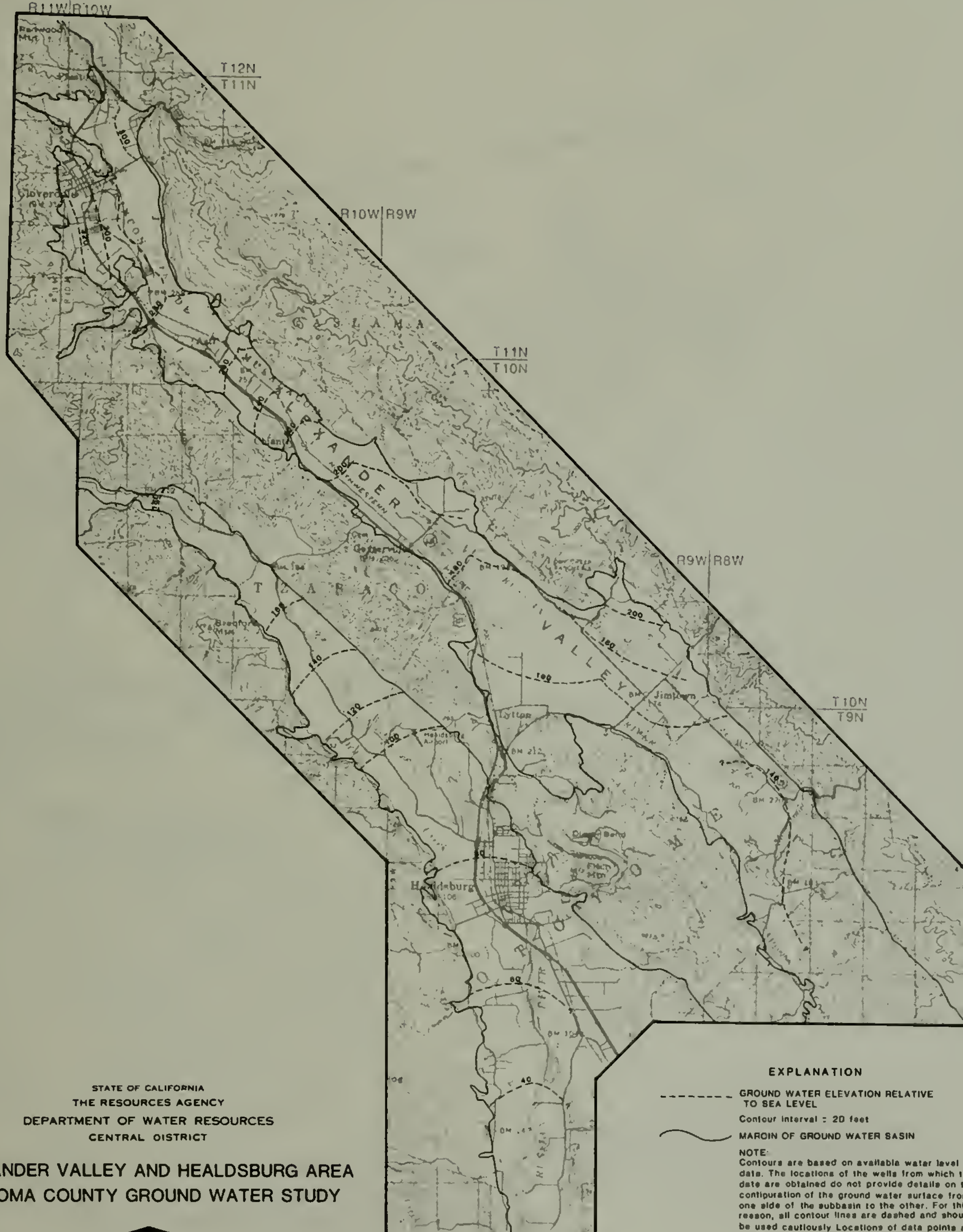
This fluctuation represents a total volume of 62 000 cubic dekametres (50,000 acre-feet) of ground water every year. Under present conditions, it possible to extract more ground water from the water-bearing materials with little or no adverse effect on the reservoir. Extraction of more ground water would increase the range of fluctuation of the ground water surface and would provide more available storage capacity for recharging water. If extractions are increased, additional monitoring wells will probably be needed to delineate the ground water surface near the margins of the subbasins so that long-term effects can be evaluated.

Table 4

SUMMARY OF GROUND WATER STORAGE CAPACITY

Ground Water Basin and Subbasin	Permeable Area	Number of Wells in Area	Total Storage Capacity	Fall of 1980 Saturated Storage	Fall of 1980 Available Storage
	(hectares)		(cubic dekametres)	(cubic dekametres)	(cubic dekametres)
Cloverdale (Nodes 1-13)	2 300	180	88 000	68 000	20 000
Alexander Area (Nodes 14-56)	8 100	600	940 000	675 000	265 000
Alexander Valley Subtotal	10 400	780	1 028 000	743 000	285 000
Healdsburg Area (Nodes 57-95)	7 700	830	603 000	481 000	122 000
Totals	18 100		1 631 000	1 224 000	407 000
	(acres)		(acre-feet)	(acre-feet)	(acre-feet)
Cloverdale (Nodes 1-13)	5,700	180	71,000	55,000	16,000
Alexander Area (Nodes 14-56)	20,100	600	762,000	547,000	215,000
Alexander Valley Subtotal	25,800	780	833,000	602,000	231,000
Healdsburg Area (Nodes 57-95)	19,000	830	489,000	390,000	99,000
Totals	44,800		1,322,000	992,000	330,000

FIGURE 10



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

ALEXANDER VALLEY AND HEALDSBURG AREA
SONOMA COUNTY GROUND WATER STUDY

GROUND WATER ELEVATION
FALL 1980

EXPLANATION

GROUND WATER ELEVATION RELATIVE TO SEA LEVEL

Contour interval : 20 feet

MARGIN OF GROUND WATER BASIN

NOTE:
Contours are based on available water level data. The locations of the wells from which the data are obtained do not provide details on the configuration of the ground water surface from one side of the subbasin to the other. For this reason, all contour lines are dashed and should be used cautiously Locations of data points are on file at Central District, DWR

STATE OF CALIFORNIA
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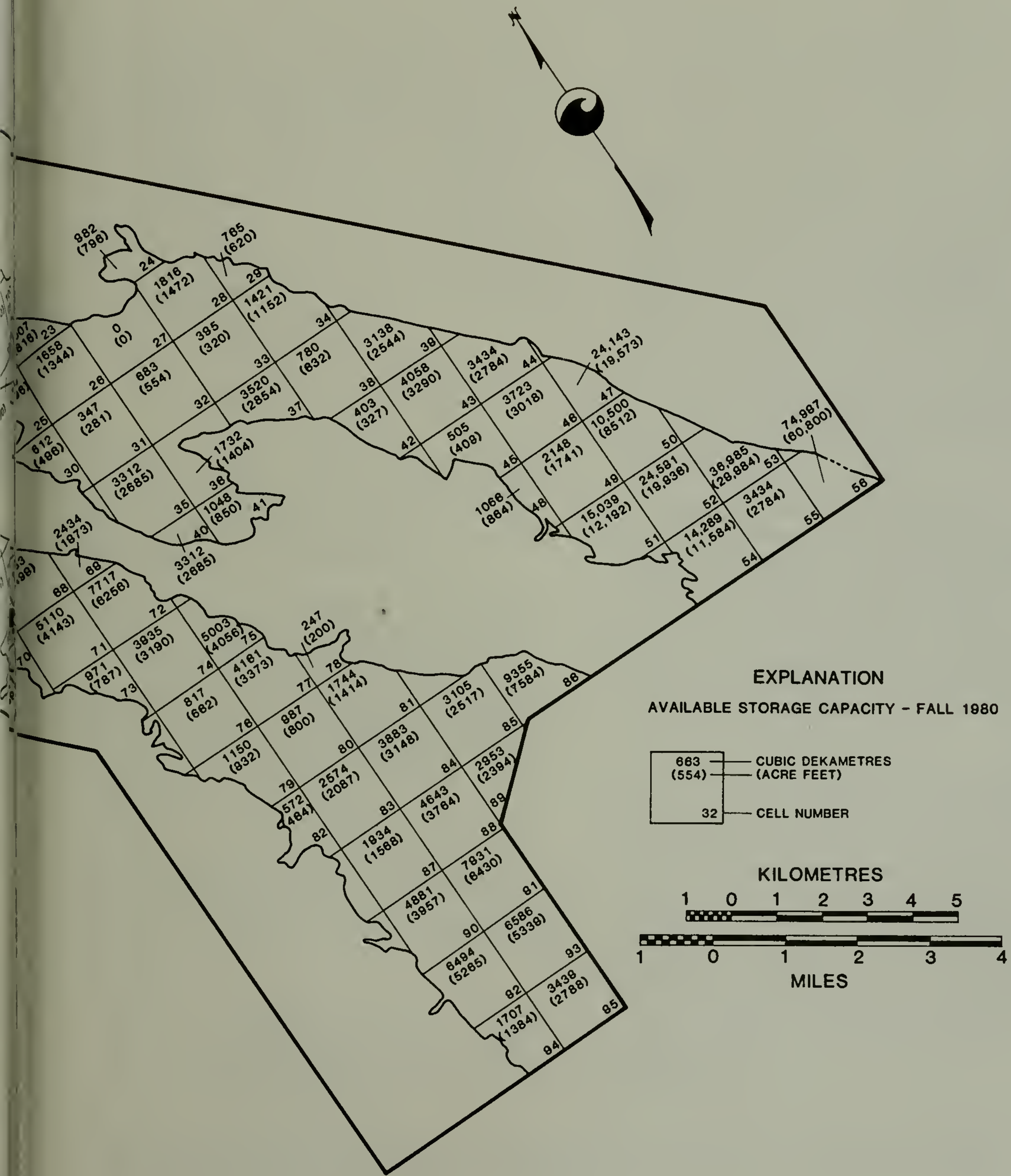
ALEXANDER VALLEY AND HEALDSBURG AREA
SONOMA COUNTY GROUND WATER STUDY

AVAILABLE STORAGE CAPACITY PER CELL

FIGURE 11


EXPLANATION
AVAILABLE STORAGE CAPACITY - FALL 1980
683 — CUBIC DEKAMETRES
(554) — (ACRE FEET)
32 — CELL NUMBER
KILOMETRES
1 0 1 2 3 4 5
1 0 1 2 3 4
MILES

Chapter 5. WATER QUALITY

The quality of a water resource is as important as the quantity. To assess the quality of the ground water in the study area, chemical analyses of water from wells in the area were compiled. Water quality data from Department of Water Resources files for 16 wells in Alexander Valley and from 2 wells in the Healdsburg area are shown in Table 5. The significance of some of the constituents present in the water is discussed in the following sections.

Dissolved Sodium and aSAR*

Sodium is a very active metal that does not occur free in nature. Most sodium salts, such as sodium chloride or table salt, are extremely soluble in water, and most natural waters contain measurable amounts of these salts.

There are some indications that higher concentrations of sodium in drinking water may be harmful to people with heart, kidney, or circulatory diseases. However, the levels of dissolved sodium that cause these problems have not been firmly determined. No drinking water standard for sodium has been established.

Sodium is required in limited amounts for most plant growth, but irrigation water with high concentrations of sodium in relation to calcium and magnesium can cause two problems. High concentrations of sodium:

° Have a toxic effect on most tree crops and woody ornamentals, either through foliar absorption or root absorption.

° Can decrease the permeability of soils with moderate to high clay content, causing poor soil drainage.

The adjusted sodium adsorption ratio (aSAR) has been developed as a means of indicating the extent of the above problems. Previous guidelines for sodium used the SAR rather than the aSAR. The new guidelines (aSAR) recommend a lower concentration of sodium than the previous guidelines.

Irrigation water will cause some soil binding in soils containing clay if the aSAR value is 6 or more and will cause severe drainage problems when the aSAR value is 9 or more.

Ion toxicity from root absorption problems increase as the aSAR exceeds 3; severe problems occur when the aSAR is greater than 9 (Ayers and Branson, 1975). Ion toxicity from foliar absorption problems increase as the aSAR exceeds 3 and becomes severe when 6 or more. Foliar absorption limits are important when sprinklers are used for irrigation or frost control.

Most of the wells studied had relatively low aSAR values. Sixteen (89 percent) had values less than two. One well (10N/9W-32R1), which is 75 metres (245 feet) deep, had aSAR values in the range of 5.18 to 5.66. That well is probably in the Dry Creek Conglomerate Formation. Another well (9N/8W-7Q1), which is 149 metres (490 feet) deep, had aSAR values that ranged from 13.31 to 16.77. Most, if not all, of that well is drilled in the Glen Ellen Formation.

*aSAR calculations were based on the procedure developed by Ayers and Branson, University of California Cooperative Extension, January 1975 "Guidelines for Interpretation of Water Quality for Agriculture".

Table 5

GROUND WATER QUALITY OF ALEXANDER VALLEY AND HEALDSBURG AREA

Date Sampled	EC (µS/cm)	pH	aSAR	Dissolved Mineral Constituents (mg/L) Ca	Mg	Na	K	TH	HCO_3	CO_3	CL	SO_4	NO_3	B	TDS
				Well 9N/8W-7Q1 (Depth 149 metres; 490 feet)											
7/--/58	583	8.2	15.52	1.0	3.0	131	4.9	16	308	0	41	0.0	0	0.34	444
9/--/59	588	8.4	15.66	4.8	1.2	134	6.2	17	292	11	38	1.0	0.2	0.4	-
9/--/60	611	8.5	16.28	4.0	1.0	138	4.0	15	243	35	42	1.0	0	0.42	-
8/21/61	551	8.3	13.31	3.7	2.2	118	5.0	18	287	0	33	0.0	0.5	0.32	-
9/19/61	586	8.8	15.11	3.6	1.0	132	4.0	13	270	22	38	1.0	1.0	0.40	416
9/23/64	583	7.6	15.69	2.6	1.3	132	5.4	12	306	0	36	1.0	0.3	0.3	425
8/31/67	623	8.6	16.77	2.8	2.2	144	-	16	298	7	40	-	-	0.5	-
7/08/69	581	8.5	15.79	4.1	0.7	130	5.8	13	299	12	18	0.5	1.2	0.5	402
7/16/70	577	8.2	15.46	3.8	1.6	132	-	16	311	0	39	-	-	-	-
7/25/73	593	7.7	15.41	-	-	128	-	12	313	0	35	-	-	-	-
6/12/75	570	8.1	14.41	-	-	125	-	17	300	0	36	-	-	-	-
8/09/78	580	8.2	16.40	-	-	139	-	12	-	-	36	-	-	-	-
7/16/80	589	8.2	15.63	2	2	132	5.3	13	-	-	37	0	0.0	0.5	436
				Well 9N/9W-1K1 (Depth 124 metres; 407 feet)											
6/12/75	347	7.7	0.78	26	23	12	0.7	162	193	0	6.0	18	2.4	0.0	209
8/03/77	298	7.9	0.97	-	-	14	-	122	172	0	6.7	-	-	-	-
7/29/80	300	8.3	0.94	22	18	14	0.7	129	-	-	6	-	-	-	-
				Well 9N/9W-1P1 (Depth 27 metres; 90 feet)											
1/08/57	413	7.6	0.85	48	20	13	1.0	203	255	0	8.5	5.8	0.1	1.3	-
7/--/58	356	8.1	0.72	28	24	11	0.3	169	191	0	11	14	10	0.10	274
9/--/59	311	8.3	0.80	25	19	12	0.8	141	172	4	4.8	11	4.8	0.0	-
9/--/60	334	8.2	0.81	21	23	13	1	148	170	0	14	13	1	0.0	-
9/--/61	304	8.0	0.67	19	23	10	0.7	144	175	0	6.2	12	2.1	0.09	-
9/19/63	272	7.7	0.88	17	19	13	0.8	122	154	0	9.0	5.0	5.0	0.0	179
9/07/66	420	8.6	0.57	35	28	9.2	-	205	182	12	8.0	-	-	0.1	-
7/12/68	403	8.5	0.59	33	28	9.4	-	199	204	6	5.0	-	-	0.0	-
7/08/69	333	8.2	0.52	28	24	8.0	0.5	167	194	0	4.3	18	4.2	0.1	150
7/16/70	360	7.8	0.48	30	24	7.6	-	176	183	0	6.4	-	-	-	-
7/26/73	388	8.1	0.58	30	26	9.2	0.6	184	192	0	6.2	28	9.8	0.0	215
6/23/76	362	8.3	0.59	-	-	9.2	-	184	205	0	6.2	-	-	-	-
8/09/78	351	8.2	0.71	-	-	11	-	166	-	-	4.6	-	-	-	-
				Well 9N/10W-1C1 (Depth 64 metres; 209 feet)											
7/--/58	222	7.8	1.40	12	12	19	0.7	79	128	0	7	3	0	0.0	164
9/--/59	204	8.0	1.28	14	9.0	18	0.6	72	124	0	5.5	1.0	0.0	0.0	-
8/--/60	225	8.4	1.43	14	11	20	1	77	101	12	10	4	0	0.11	-
9/--/61	216	7.8	1.29	15	9.1	18	0.8	75	129	0	6.8	0.0	0.2	0.02	-
9/06/66	208	8.3	1.23	13	12	18	-	80	116	0	50	-	-	0.0	-
9/06/67	215	8.6	1.26	14	9.7	18	-	75	112	4	6.4	-	-	0.0	-
7/30/68	212	8.1	1.25	13	10	18	-	74	117	0	6.7	-	-	0.1	-
7/08/69	208	8.1	1.21	12	10	17	0.5	71	121	0	6.9	2.1	0.0	0.0	175
7/16/70	204	7.9	1.35	13	9.4	19	-	71	118	0	6.8	-	-	-	-
7/26/73	208	7.5	1.14	-	-	16	-	71	119	0	6.3	-	-	-	-
6/12/75	208	8.0	1.20	-	-	17	-	71	117	0	7.5	-	-	-	-
8/04/77	230	8.3	1.44	-	-	20	-	73	127	0	8.9	-	-	-	-
7/12/79	232	8.2	1.42	14	10	20	0.7	76	(103)T	-	8	6	0.0	0.0	172
				Well 9N/10W-1L1 (Depth 64 metres; 209 feet)											
9/19/63	539	8.5	0.79	29	51	13	0.6	283	298	11	10	17	17	0.1	333
				Well 10N/9W-18B1 (Depth 55 metres; 180 feet)											
8/10/72	306	7.9	1.09	20	16	17	0.3	118	125	0	12	18	22	0.0	187
8/08/74	288	7.0	1.02	-	-	16	-	115	119	0	9.4	-	-	-	-
8/03/77	431	8.3	1.00	-	-	16	-	228	253	0	9.5	-	-	-	-
7/16/80	304	7.2	1.00	23	14	16	0.4	115	110	-	11	-	-	-	-
				Well 10N/9W-18N1 (Depth 20 metres; 66 feet)											
6/23/76	345	8.5	1.02	26	20	16	0.6	147	151	0	7.6	38	9.0	0.1	228
8/09/78	373	8.2	1.05	-	-	17	-	154	(120)T	-	6.0	-	-	-	-
				Well 10N/9W-18R1 (Depth 4.3 metres; 14 feet)											
7/--/58	336	8.0	0.56	32	22	9	0.7	169	204	0	5	6	2	0.7	254
9/--/59	297	8.1	0.56	29	18	8.4	0.9	146	170	0	4.8	13	5.3	0.5	-
9/19/63	329	8.6	0.55	31	22	8.5	0.7	170	170	10	6.5	13	5.6	0.4	202
9/23/64	292	8.5	0.56	34	14	8.5	1.2	141	150	8	4.5	13	0.2	0.4	154

Table 5 (continued)

Date Sampled	EC (µS/cm)	pH	aSAR	Dissolved Mineral Constituents (mg/L) Ca	Mg	Na	K	TH	HCO_3	CO_3	CL	SO_4	NO_3	B	TDS
				Well 10N/9W-26L1 (Depth 98 metres; 320 feet)											
7/--/58	502	8.4	0.80	28	45	13	0.3	256	281	10.5	14	11	14	0.01	384
9/--/59	479	8.5	0.73	28	47	12	0.3	263	278	14	5.8	11	13	0.0	-
? /62	513	8.4	0.74	29	47	12	0.4	265	300	6	8.3	12	13	0.17	-
9/23/64	527	8.5	0.67	22	53	11	0.4	274	275	16	7.0	16	13	0.5	325
8/03/65	563	8.7	0.77	29	52	13	-	286	284	14	8.6	-	-	0.1	-
9/07/66	566	8.7	0.71	32	53	12	-	299	282	17	9.7	-	-	0.1	-
8/31/67	622	8.6	0.70	34	55	12	-	313	301	13	8.7	-	-	0.1	-
7/12/68	625	8.3	0.75	33	55	13	-	311	320	0	8.6	-	-	0.0	-
7/08/69	568	8.6	0.66	30	57	11	0.5	309	310	18	8.0	32	19	0.1	307
7/16/70	578	8.3	0.65	31	56	11	-	307	324	0	9.7	-	-	-	-
8/08/74	672	8.1	0.66	-	-	12	-	346	292	0	7.7	-	-	-	-
6/23/76	597	8.2	0.75	-	-	13	-	311	304	0	11	-	-	-	-
8/09/78	639	8.1	0.62	-	-	11	-	331	(245)T	-	6.1	-	-	-	-
				Well 10N/09W-26L2 (Depth 12 metres; 40 feet)											
7/25/73	535	8.0	0.62	30	44	11	0.1	258	193	0	10	73	37	0.1	322
6/12/75	538	8.0	0.67	-	-	12	-	268	204	0	15	-	-	-	-
8/03/77	454	8.1	0.65	-	-	11	-	256	242	0	8.4	-	-	-	-
7/16/80	544	7.6	0.69	31	45	12	0.2	263	218	0	16	-	-	-	-
				Well 10N/9W-32R1 (Depth 75 metres; 245 feet)											
7/--/58	457	8.1	5.18	36	10	69	0.7	130	294	0	15	16	0	0.62	364
9/--/59	506	8.2	5.29	37	7.9	70	3.4	125	289	0	12	24	1.6	0.4	-
9/--/60	457	8.3	5.66	20	10	71	1	89	234	0	13	25	0	0	-
				Well 10N/9W-33D1 (Depth 30 metres; 98 feet)											
8/09/72	288	7.9	0.73	18	20	11	0.3	128	150	0	8.3	13	7.7	0.0	162
8/08/74	304	7.9	0.78	-	-	12	-	137	155	0	7.6	-	-	-	-
6/23/76	310	8.1	0.84	-	-	12	-	141	162	0	8.0	-	-	-	-
7/12/79	324	8.2	0.68	21	22	11	-	143	161	0	8	-	-	-	-
				Well 10N/10W-12G1 (Depth 10 metres; 33 feet)											
6/12/75	387	7.8	0.56	33	27	8.8	0.8	193	236	0	0.0	12	1.1	0.2	219
8/03/77	384	8.2	0.52	-	-	8.7	-	218	199	0	8.2	-	-	-	-
7/16/80	455	7.5	0.69	40	31	11	0.9	228	268	0	5	-	-	-	-
				Well 10N/10W-13K5 (Depth 52 metres; 172 feet)											
8/08/74	512	8.3	1.63	44	27	25	0.7	220	309	0	3.8	15	1.6	0.1	313
				Well 11N/10W-8P1 (Depth 9.1 metres; 30 feet)											
8/09/72	419	7.9	0.62	28	30	10	0.2	192	177	0	8.8	40	18	0.4	254
8/08/74	359	8.0	0.62	-	-	9.8	-	168	164	0	6.2	-	-	-	-
6/23/76	384	8.1	0.69	-	-	11	-	187	189	0	7.2	-	-	-	-
8/09/78	421	8.2	0.66	-	-	11	-	199	174	0	8.1	-	-	-	-
7/16/80	353	7.5	0.56	25	25	9	0.6	166	163	0	6	-	-	-	-
				Well 11N/10W-28N1 (Depth 5.8 metres; 19 feet)											
7/--/58	387	8.1	0.78	47	17	12	0.7	189	235	0	12	9	0	0.35	304
9/--/59	399	8.0	0.71	47	20	11	1.0	199	246	0	8.4	12	0.2	0.2	-
9/--/61	364	8.1	0.62	43	17	9.4	1.0	178	222	0	4.6	9.4	0.6	0.29	-
9/19/63	366	8.3	0.64	44	18	9.8	1.0	183	222	2	7.5	12	1.4	0.3	229
9/23/64	305	7.7	0.57	28	18	8.5	0.9	144	180	0	4.2	1.0	0.3	0.4	194
9/08/69	318	8.2	0.61	32	16	9.2	1.3	148	181	0	4.9	17	0.5	0.3	161
7/15/70	388	8.2	0.62	45	21	9.6	-	198	233	0	7.6	-	-	-	-
8/08/74	440	8.2	0.64	-	-	10	-	222	267	0	4.8	-	-	-	-
6/23/76	454	8.2	0.75	-	-	12	-	234	270	0	9.1	-	-	-	-
7/12/79	386	8.1	0.70	44	18	11	1.0	184	204	0	9	23	4.0	0.8	228
				Well 11N/10W-33A1 (Depth 6.1 metres; 20 feet)											
7/--/58	266	7.5	0.81	23	14	12	1.0	115	147	0	13	5	0	1.15	204
9/--/59	248	8.2	0.75	24	12	11	1.4	111	144	0	7.5	9.0	0.6	0.6	-
9/--/61	229	7.8	0.62	22	12	9.2	1.2	103	134	0	4.6	5.1	0.8	0.67	-
9/19/63	379	8.4	1.59	31	21	24	1.5	165	206	5	18	9.0	0.9	4.2	298
				Well 11N/10W-33G1 (Depth 5.3 metres; 18 feet)											
7/--/58	239	7.6	1.07	13	8	18	1.0	65	63	0	30	7	11	0.80	164
9/--/59	183	7.0	0.76	9.2	6.3	16	0.6	49	40	0	24	4.0	14	0.0	-
9/--/61	199	6.9	0.82	10	8.3	15	0.9	59	55	0	21	4.4	20	0.07	-
9/19/63	178	8.1	0.77	9.6	6.3	15	1.6	50	47	0	18	3.0	25	0.1	138
9/23/64	194	6.6	0.78	11	6.0	14	0.7	52	55	0	17	1.0	14	0.1	130
8/03/65	192	7.0	0.87	11	7.4	16	-	58	54	0	17	-	-	0.0	-
9/06/66	185	7.7	0.84	14	8.3	16	-	69	50	0	20	-	-	0.0	-
8/31/67	201	7.6	0.95	12	8.3	16	-	64	63	0	18	-	-	0.2	-
7/12/68	199	7.8	0.98	12	6.3	17	-	56	61	0	18	-	-	0.1	-
7/27/71	193	7.4	0.81	11	7.4	14	-	58	62	0	19	-	-	-	-

Dissolved Chloride

Chloride is the ionized form of the element chlorine, and is present in nearly all natural waters. It may come from natural mineral origin, from sea water intrusion, from leaching of agricultural salts, animal sewage, or industrial wastes. Chlorides in drinking water are not harmful until very high concentrations are reached. Restrictions are based on taste preferences. The recommended maximum concentration of chloride ion in drinking water of 250 mg/L (see Table 6).

Deciduous tree crops are sensitive to chlorides in irrigation water when applied by sprinklers, with increasing leaf damage occurring in the concentration range 142 to 355 mg/L. These problems become severe when concentrations are greater than 355 mg/L (Ayers and Branson, 1975).

Water in the wells studied contained low levels of chloride. The highest chloride concentration was 50 mg/L, and water from 15 wells (83 percent) had chloride concentrations less than 20 mg/L.

Table 6

MINERALIZATION, SECONDARY DRINKING WATER STANDARDS

Constituent and Units	Maximum Level: Recommended	Upper	Short Term
Total Dissolved Solids (mg/L)	500	1,000	1,500
or			
Specific Conductance (microsiemens)	900	1,600	2,200
Chloride (mg/L)	250	500	600
Sulfate (mg/L)	250	500	600

Source: Title 22, California Administrative Code, Chapter 15, Article 8, Section 64473.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the various minerals dissolved in water. Drinking water with a high TDS is likely to have an unpleasant appearance, taste, or odor. An upper level of 1,000 mg/L TDS has been established in the secondary drinking water standards (see Table 6). The maximum concentration of TDS in the wells studied was 444 mg/L; the minimum was 130 mg/L.

Electrical Conductivity

Electrical conductivity (EC) is a measure of the ability of water to conduct electricity. This parameter was formerly called specific conductance.

As the amount of dissolved minerals increases in water, so does conductivity. Therefore, this test is used as an indirect measurement of total dissolved solids. The conductivity of distilled water is nearly zero. The secondary drinking water standard upper limit for EC is i 600 microsiemens per centimetre (uS/cm) (see Table 6). For the wells studied, the maximum EC found was 672 uS/cm and the minimum was 178 uS/cm.

Dissolved Nitrates

Nitrates are introduced into ground water by leaching and percolation of aerobically stabilized organic nitrogen, applied fertilizers, sewage from leachfields, and the fecal materials of livestock and poultry. Waters used for domestic purposes are considered unsafe for infants when the nitrate concentration exceeds 45 mg/L, which can cause methemoglobinemia, or oxygen deficiency, in infants.

None of the wells studied in Alexander Valley or the Healdsburg area produced water with nitrate levels exceeding 45 mg/L. The highest nitrate concentration was 37 mg/L, and 15 wells (83 percent) had concentrations lower than 20 mg/L.

Dissolved Boron

Boron in drinking water is not generally regarded as a health hazard. Concentrations up to 30 mg/L have not been harmful to humans. Although a minor constituent of most water, boron is extremely important in agriculture. Small amounts of boron are essential to plant growth, but excessive amounts are harmful. Some of the plants most sensitive to boron are citrus, grapes, apples, and walnuts. Boron concentrations below 0.5 mg/L are satisfactory for all crops, and a concentration of 0.5 mg/L is usually not harmful (Ayers and Branson, 1975).

High boron concentrations can be caused by:

° Household products percolating from septic tank leachfields.

° Connate waters.

° Water rising from great depths along fault zones.

° Volcanic activity.

° Sea water intrusion.

° Buried soil horizons containing boron salts that contaminate percolating ground water.

Six of the wells (33 percent of the total) had boron levels greater than 0.5 mg/L at least one of the times they were sampled; however, five of these wells had boron concentrations less than 0.5 mg/L at other times.

The sixth well (11N/10W-33A1) had boron concentrations that ranged from 0.6 to 4.2 mg/L. This well was shallow, 6 metres (20 feet), and would, therefore, be fairly susceptible to pollution by septic tank leachfields or wastes discharged to the nearby ground surface.

Dissolved Hardness

Hardness, a measurement of the soap-neutralizing capability of water, is caused primarily by the presence of calcium and magnesium ions. The detrimental effects of hardness are excessive soap consumption and formation of scums in laundering; toughening of vegetables cooked in hard water; and formation of scale in hot water heaters, boilers, and pipes. Hard water also contributes to increased detergent consumption, but without the formation of scums. Scale is formed by precipitation of calcium and magnesium bicarbonates, resulting in the formation of insoluble carbonates on the heated interiors of pipes and water heaters. Drinking hard water appears to have no harmful effects.

Hardness values are expressed as milligrams per litre (mg/L) of calcium carbonate. These values indicate the amount of dissolved calcium carbonate necessary to give a degree of hardness equivalent to the water being tested. The maximum concentration of hardness in wells in the study area was 346 mg/L; the minimum concentration was 12 mg/L.

Most ground water in the study area may be classified as moderately hard to hard, according to the following Department of Water Resources classification system:

Hardness as mg/L $CaCO_3$	Relative Classification
0 - 100	Soft
101 - 200	Moderately Hard
>200	Hard

pH

pH is a measure of the hydrogen ion concentration of a solution. It is important because the pH of water affects its taste, water treatment

processes, chlorination efficiency, and corrosiveness. A pH value of 7 is neutral, values less than 7 are acid, and values greater than 7 are alkaline. The pH values for the wells sampled ranged from a maximum of 8.8 to a minimum of 6.7. Water with pH values in that range should be satisfactory for most uses.

Surface Water Quality

There are two major streams in the study areas. The Russian River runs throughout Alexander Valley and through the lower portion of the Healdsburg area. Dry Creek runs through the upper portion of the Healdsburg area.

Many of the wells studied were drilled in the alluvial deposits near one of these streams. These alluvial deposits, and possibly some of the other geologic formations, receive recharge water from the two streams. It is likely that the water quality of the streams has a significant effect on the ground water quality of the two study areas.

The Department of Water Resources started sampling the Russian River near Healdsburg in April 1951. Mean values (not weighted for flow) were calculated by the U. S. Geological Survey for the 114 samples collected from April 1951 through September 1962. Their calculated means are shown below:

Sodium	9.14 mg/L
Bicarbonate	134 mg/L
Chloride	5.82 mg/L
Boron	0.73 mg/L
EC	244 uS/cm
Hardness (as $CaCO_3$)	110 mg/L

A flow-weighted mean EC for the same station, calculated for January 1961 through November 1966, was 147 uS/cm.

The U. S. Geological Survey began sampling Dry Creek below Pena Creek in October 1970. Mean values (not weighted for flow) were calculated for some of the data generated at this station for October 1970 through June 1975. These means are tabulated below:

Sodium	10 mg/L
Bicarbonate	121 mg/L
Chloride	4.8 mg/L
Boron	0.26 mg/L
EC	224 uS/cm
Hardness (as $CaCO_3$)	110 mg/L

Well Owners' Perceptions

To determine well owners' opinions of their ground water quality, Sonoma County Water Agency mailed questionnaires in 1977 to all property owners in Sonoma County who were not served by a municipal or mutual water system. The questionnaire requested information on taste, odor, and color of ground water. The responses were grouped according to assessor's parcel books (Figure 12). Within each parcel book area responses were separated according to well depth:

° Shallow wells, 0-46 metres (0-150 feet) deep

° Intermediate wells, 46-107 metres (151-350 feet) deep

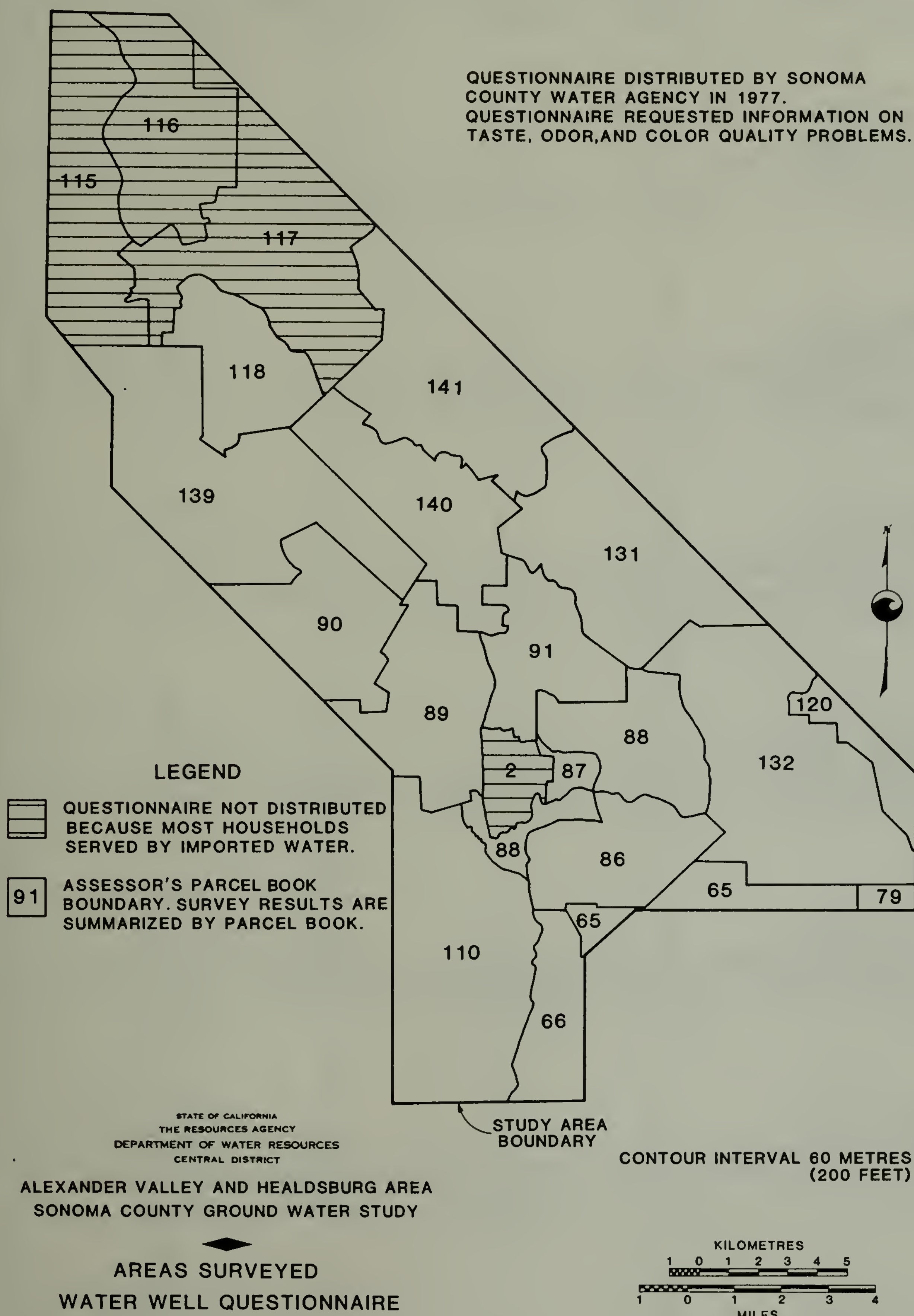
° Deep wells, greater than 107 metres (350 feet) deep

Within each depth range, the number of wells with each of the following problems was tabulated: taste, odor, color, other problems, and none (no problem).

Since a single well could have more than one problem, two other tabulations were added: (1) taste, odor, or color; and (2) taste, color, or other. Responses to the questionnaire are tabulated on Table 7.

The most common complaints were color and taste. Color in water can be caused by excessive iron and manganese. Unpleasant taste can be caused by excessive hardness, salinity, sodium, iron and manganese, or sulfides. Unpleasant odor can be caused by excessive iron and manganese or hydrogen sulfide.

FIGURE 12



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

ALEXANDER VALLEY AND HEALDSBURG AREA
SONOMA COUNTY GROUND WATER STUDY

AREAS SURVEYED
WATER WELL QUESTIONNAIRE

Table 7

WATER WELL QUESTIONNAIRE RESPONSES

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
ASSESSORS PARCEL BOOK NO. 57 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	15	1	0	7	23
ODOR	16	2	0	11	29
COLOR	14	1	0	7	22
OTHER	15	1	0	4	20
NONE	25	11	0	13	49
TASTE, ODOR OR COLOR	24	4	0	16	44
TASTE, ODOR, COLOR OR OTHER	32	4	0	16	52
NUMBER OF WELLS IN SURVEY	57	15	0	29	101
% WELLS WITH T.O.C QUALITY PROBLEM	42.1%	26.7%	N/A	55.2%	43.6%
% WELLS WITH T.O.C.X QUALITY PROBLEM	56.1%	26.7%	N/A	55.2%	51.5%
ASSESSORS PARCEL BOOK NO. 59 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	17	2	0	9	28
ODOR	11	2	0	7	20
COLOR	16	2	0	13	31
OTHER	10	3	0	3	16
NONE	44	13	1	16	74
TASTE, ODOR OR COLOR	23	3	0	13	39
TASTE, ODOR, COLOR OR OTHER	31	5	0	15	51
NUMBER OF WELLS IN SURVEY	75	18	1	31	125
% WELLS WITH T.O.C QUALITY PROBLEM	30.7%	16.7%	.0%	41.9%	31.2%
% WELLS WITH T.O.C.X QUALITY PROBLEM	41.3%	27.8%	.0%	48.4%	40.8%
ASSESSORS PARCEL BOOK NO. 65 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	21	12	3	4	40
ODOR	15	9	2	3	29
COLOR	20	11	2	6	39
OTHER	14	2	1	1	18
NONE	34	14	3	20	71
TASTE, ODOR OR COLOR	33	18	5	7	63
TASTE, ODOR, COLOR OR OTHER	39	19	5	8	71
NUMBER OF WELLS IN SURVEY	73	33	8	28	142
% WELLS WITH T.O.C QUALITY PROBLEM	45.2%	54.5%	62.5%	25.0%	44.4%
% WELLS WITH T.O.C.X QUALITY PROBLEM	53.4%	57.6%	62.5%	28.6%	50.0%
ASSESSORS PARCEL BOOK NO. 66 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	21	2	2	9	34
ODOR	15	2	0	7	24
COLOR	24	2	0	4	30
OTHER	15	4	0	8	27
NONE	82	7	1	20	110
TASTE, ODOR OR COLOR	32	3	2	10	47
TASTE, ODOR, COLOR OR OTHER	42	6	2	15	65
NUMBER OF WELLS IN SURVEY	124	13	3	35	175
% WELLS WITH T.O.C QUALITY PROBLEM	25.8%	23.1%	66.7%	28.6%	26.9%
% WELLS WITH T.O.C.X QUALITY PROBLEM	33.9%	46.2%	66.7%	42.9%	37.1%
ASSESSORS PARCEL BOOK NO. 78 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	4	8	0	2	14
ODOR	2	6	0	2	12
COLOR	6	16	1	5	28
OTHER	3	1	1	3	8
NONE	6	18	0	4	26
TASTE, ODOR OR COLOR	9	17	1	5	32
TASTE, ODOR, COLOR OR OTHER	12	18	1	7	38
NUMBER OF WELLS IN SURVEY	18	36	1	11	66
% WELLS WITH T.O.C QUALITY PROBLEM	50.0%	47.2%	100.0%	45.5%	48.5%
% WELLS WITH T.O.C.X QUALITY PROBLEM	66.7%	50.0%	100.0%	63.6%	57.6%
ASSESSORS PARCEL BOOK NO. 81 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	0	0	0	1	1
ODOR	0	0	0	1	1
COLOR	0	0	0	1	1
OTHER	0	0	0	0	0
NONE	0	0	0	0	0
TASTE, ODOR OR COLOR	0	0	0	2	2
TASTE, ODOR, COLOR OR OTHER	0	0	0	2	2
NUMBER OF WELLS IN SURVEY	0	0	0	2	2
% WELLS WITH T.O.C QUALITY PROBLEM	N/A	N/A	N/A	100.0%	100.0%
% WELLS WITH T.O.C.X QUALITY PROBLEM	N/A	N/A	N/A	100.0%	100.0%
ASSESSORS PARCEL BOOK NO. 83 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM					
TASTE	10	3	0	2	15
ODOR	6	3	0	0	9
COLOR	8	2	0	1	11
OTHER	5	0	0	0	5
NONE	6	1	1	4	12
TASTE, ODOR OR COLOR	13	4	0	3	20
TASTE, ODOR, COLOR OR OTHER	15	4	0	3	22
NUMBER OF WELLS IN SURVEY	21	5	1	7	34
% WELLS WITH T.O.C QUALITY PROBLEM	61.9%	80.0%	.0%	42.9%	58.8%
% WELLS WITH T.O.C.X QUALITY PROBLEM	71.4%	80.0%	.0%	42.9%	64.7%

Table 7 (Continued)

ASSESSORS PARCEL BOOK NO. 86 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	2	0	2	4
ODOR	0	1	0	1	2
COLOR	0	2	0	0	2
OTHER	0	2	0	1	3
NONE	16	3	0	2	21
TASTE, ODOR OR COLOR	0	3	0	2	5
TASTE, ODOR, COLOR OR OTHER	0	5	0	3	8
NUMBER OF WELLS IN SURVEY	16	8	0	5	29
% WELLS WITH T,O,C QUALITY PROBLEM	.0%	37.5%	N/A	40.0%	17.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	.0%	62.5%	N/A	60.0%	27.6%

ASSESSORS PARCEL BOOK NO. 87 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	0	0	0	0
ODOR	0	0	0	0	0
COLOR	0	0	0	0	0
OTHER	0	0	0	0	0
NONE	1	0	0	1	2
TASTE, ODOR OR COLOR	0	0	0	0	0
TASTE, ODOR, COLOR OR OTHER	0	0	0	0	0
NUMBER OF WELLS IN SURVEY	1	0	0	1	2
% WELLS WITH T,O,C QUALITY PROBLEM	.0%	N/A	N/A	.0%	.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	.0%	N/A	N/A	.0%	.0%

ASSESSORS PARCEL BOOK NO. 88 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	0	0	1	1
ODOR	0	0	0	1	1
COLOR	0	1	0	1	2
OTHER	0	1	0	0	1
NONE	20	1	0	9	30
TASTE, ODOR OR COLOR	0	1	0	2	3
TASTE, ODOR, COLOR OR OTHER	0	2	0	2	4
NUMBER OF WELLS IN SURVEY	20	3	0	11	34
% WELLS WITH T,O,C QUALITY PROBLEM	.0%	33.3%	N/A	18.2%	8.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	.0%	66.7%	N/A	18.2%	11.8%

ASSESSORS PARCEL BOOK NO. 89 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	5	0	0	1	6
ODOR	2	0	0	2	4
COLOR	15	0	0	2	17
OTHER	5	1	0	5	11
NONE	36	11	0	11	58
TASTE, ODOR OR COLOR	17	0	0	3	20
TASTE, ODOR, COLOR OR OTHER	21	1	0	8	30
NUMBER OF WELLS IN SURVEY	57	12	0	19	88
% WELLS WITH T,O,C QUALITY PROBLEM	29.8%	.0%	N/A	15.8%	22.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	36.8%	6.3%	N/A	42.1%	34.1%

ASSESSORS PARCEL BOOK NO. 90 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	4	1	0	0	5
ODOR	3	0	0	0	3
COLOR	9	1	0	1	11
OTHER	1	0	0	0	1
NONE	32	1	1	5	39
TASTE, ODOR OR COLOR	11	2	0	1	14
TASTE, ODOR, COLOR OR OTHER	12	2	0	1	15
NUMBER OF WELLS IN SURVEY	44	3	1	6	54
% WELLS WITH T,O,C QUALITY PROBLEM	25.0%	66.7%	.0%	16.7%	25.9%
% WELLS WITH T,O,C,X QUALITY PROBLEM	27.3%	66.7%	.0%	16.7%	27.8%

ASSESSORS PARCEL BOOK NO. 110 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	8	1	0	3	12
ODOR	8	0	0	3	11
COLOR	11	1	0	2	14
OTHER	6	0	0	1	7
NONE	44	1	0	7	52
TASTE, ODOR OR COLOR	14	1	0	4	19
TASTE, ODOR, COLOR OR OTHER	18	1	0	4	23
NUMBER OF WELLS IN SURVEY	62	2	0	11	75
% WELLS WITH T,O,C QUALITY PROBLEM	22.6%	50.0%	N/A	36.4%	25.3%
% WELLS WITH T,O,C,X QUALITY PROBLEM	29.0%	50.0%	N/A	36.4%	30.7%

ASSESSORS PARCEL BOOK NO. 118 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	2	0	1	0	3
ODOR	2	0	1	0	3
COLOR	4	0	1	0	5
OTHER	1	0	0	0	1
NONE	2	0	0	1	3
TASTE, ODOR OR COLOR	4	0	1	0	5
TASTE, ODOR, COLOR OR OTHER	4	0	1	0	5
NUMBER OF WELLS IN SURVEY	6	0	1	1	8
% WELLS WITH T,O,C QUALITY PROBLEM	66.7%	N/A	100.0%	.0%	62.5%
% WELLS WITH T,O,C,X QUALITY PROBLEM	65.7%	N/A	100.0%	.0%	62.5%

Table 7 (Continued)

ASSESSORS PARCEL BOOK NO. 120 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	12	7	2	3	24
ODOR	11	7	2	4	24
COLOR	14	10	0	5	29
OTHER	4	8	0	2	14
NONE	17	13	2	5	37
TASTE, ODOR OR COLOR	18	13	2	5	38
TASTE, ODOR, COLOR OR OTHER	20	17	2	7	46
NUMBER OF WELLS IN SURVEY	37	30	4	12	83
% WELLS WITH T,O,C QUALITY PROBLEM	48.6%	43.3%	50.0%	41.7%	45.8%
% WELLS WITH T,O,C,A QUALITY PROBLEM	54.1%	56.7%	50.0%	58.3%	55.4%

ASSESSORS PARCEL BOOK NO. 131 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	3	2	1	0	6
ODOR	2	2	0	0	4
COLOR	3	1	0	1	5
OTHER	6	1	0	3	10
NONE	36	8	5	11	60
TASTE, ODOR OR COLOR	6	2	1	1	10
TASTE, ODOR, COLOR OR OTHER	12	3	1	4	20
NUMBER OF WELLS IN SURVEY	48	11	6	15	80
% WELLS WITH T,O,C QUALITY PROBLEM	12.5%	18.2%	16.7%	6.7%	12.5%
% WELLS WITH T,O,C,A QUALITY PROBLEM	25.0%	27.3%	16.7%	26.7%	25.0%

ASSESSORS PARCEL BOOK NO. 132 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	12	7	0	5	24
ODOR	9	5	0	5	19
COLOR	15	3	1	3	27
OTHER	9	1	1	4	15
NONE	11	2	2	5	20
TASTE, ODOR OR COLOR	17	11	1	5	34
TASTE, ODOR, COLOR OR OTHER	20	11	2	5	38
NUMBER OF WELLS IN SURVEY	31	13	4	10	58
% WELLS WITH T,O,C QUALITY PROBLEM	54.8%	84.6%	25.0%	50.0%	58.6%
% WELLS WITH T,O,C,X QUALITY PROBLEM	64.5%	84.6%	50.0%	50.0%	65.5%

ASSESSORS PARCEL BOOK NO. 139 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	4	1	0	0	5
ODOR	4	0	0	0	4
COLOR	3	0	0	0	3
OTHER	1	0	0	0	1
NONE	7	0	0	5	12
TASTE, ODOR OR COLOR	4	1	0	0	5
TASTE, ODOR, COLOR OR OTHER	4	1	0	0	5
NUMBER OF WELLS IN SURVEY	11	1	0	5	17
% WELLS WITH T,O,C QUALITY PROBLEM	36.4%	100.0%	N/A	.0%	29.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	36.4%	100.0%	N/A	.0%	29.4%

ASSESSORS PARCEL BOOK NO. 140 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	5	1	0	0	6
ODOR	6	1	0	0	7
COLOR	4	1	0	1	6
OTHER	1	0	0	0	1
NONE	24	0	0	9	33
TASTE, ODOR OR COLOR	8	1	0	1	10
TASTE, ODOR, COLOR OR OTHER	9	1	0	1	11
NUMBER OF WELLS IN SURVEY	33	1	0	10	44
% WELLS WITH T,O,C QUALITY PROBLEM	24.2%	100.0%	N/A	10.0%	22.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	27.3%	100.0%	N/A	10.0%	25.0%

ASSESSORS PARCEL BOOK NO. 141 QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
TASTE	1	0	0	1	2
ODOR	1	0	0	1	2
COLOR	2	0	1	0	3
OTHER	1	0	0	0	1
NONE	4	3	0	3	10
TASTE, ODOR OR COLOR	2	0	1	1	4
TASTE, ODOR, COLOR OR OTHER	3	0	1	1	5
NUMBER OF WELLS IN SURVEY	7	3	1	4	15
% WELLS WITH T,O,C QUALITY PROBLEM	28.6%	.0%	100.0%	25.0%	26.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	42.9%	.0%	100.0%	25.0%	33.3%

Ground water level measurements from more wells in the area would undoubtedly allow better estimates of the total water in storage and more precise definition of the hydrology and chemistry of the sub-basins, but the present ground water monitoring network is probably adequate as long as present water management practices continue.

Ground Water Measurements

To accurately evaluate the ground water potential of an area, a wide areal distribution of ground water level data, gathered over a long period, is necessary. This information can be used to determine the overall condition of the sub-basin or basin and to define areas of stable, increasing, or decreasing ground water levels. The information can also be used to evaluate the effects of geologic structures, such as faults and geologic formations. Ground water level maps constructed from these data permit a more accurate estimate of the total ground water in storage.

At present, 22 wells are being monitored for water level or water quality by the Department of Water Resources and the U. S. Geological Survey. The Department measures water levels in 13 wells in Alexander Valley. Of these wells, 8 are also monitored for water quality. The Geological Survey measures water levels in 9 wells in the Healdsburg area but does not take samples for water quality analysis.

If a monitored well is destroyed, or for some other reason becomes unmeasurable, it should be replaced with a nearby well that measures the water level in the same aquifer zone.

Before a well is added to the monitoring network, construction details of that well must be evaluated to ensure the new well is measuring the same aquifer. Construction data necessary are total depth of the well, length of casing, perforated interval, and length of gravel pack, if any.

The existing monitoring network appears to be adequate for the present pumping patterns, pumping rates, and recharge rates. The well hydrographs in Figure 8 show only a 3-metre 10-foot fluctuation in ground water levels, which recover each year to about the same level. No long term decline is apparent.

After several years of measurement, data from the network can be analyzed to better define basin hydrology, including the role of faults in ground water movement and the extent of aquifer connection. After such analysis, the monitoring network can be reevaluated. Those wells no longer necessary can be dropped, and the remaining wells can be monitored on a permanent basis.

However, if the fluctuation of ground water levels increases significantly, or if water levels begin to decline and do not recover over the long term, additional monitoring wells might be needed in the network.

Similarly, ground water levels and water chemistry should be reevaluated sometime after Warm Springs Dam becomes operational so that any possible effects of the dam on ground water quantity or quality can be ascertained.

Natural Recharge

Recharge is the movement of water from land surfaces and streambeds into underlying aquifers. It occurs in response to withdrawal of ground water from those aquifers, availability of surface water,

and precipitation. Several physical factors control the potential for recharge in an area: the slope of the land surface, the permeability of the soils, the subsurface geology, and the amount of storage space available in the aquifer.

According to Muir and Johnson (1979), the slope of the land surface should be less than 15 percent and the percolating rate of the soil profile should exceed 1.5 centimetre (0.6 inch) per hour for recharge to take place. If the slope is greater than 15 percent, rapid runoff greatly reduces the recharge potential. For an appreciable amount of water to penetrate the soil, the infiltration rate must be relatively rapid.

The soils in most of Alexander Valley and the Healdsburg area have a permeability greater than 1.5 centimetre (0.6 inch) per hour and the slopes are well below 15 percent (Miller 1972). Therefore, most of the study area is suitable for recharge.

Subsurface geology is the second important factor in evaluating a recharge area and is the most difficult to determine. Good aquifer connection between the area of recharge and the area of use is necessary so that the ground water can travel from the recharge site to the area where it is extracted.

The ground water level measurement network now being monitored by the Department of Water Resources and U. S. Geological Survey may provide information on the hydraulic continuity of the aquifers. At selected locations in the study area, 24-hour, constant-rate pump tests are recommended to determine hydraulic characteristics of the basin sediments, as well as to establish the presence of any ground water barriers, such as faults.

The study area appears to accept natural recharge up to the limit of usable storage capacity. Hydrographs indicate that current recharge is equivalent to the amount of water that is discharged each year.

No need for artificial recharge is apparent or foreseeable at this time unless the flow of Russian River and its tributaries is sharply curtailed or diverted for other uses, or if there is a significant change in the location and amounts of ground water extraction.

Ground Water Recharge Rate

Sustained yield is the amount of water that can be extracted annually from a ground water basin without adverse effects. The sustained yield of a basin is generally equal to the long term annual recharge. Most of the seasonal recharge in Alexander Valley is a result of rainfall and of recharge from the Russian River. For the Healdsburg area, recharge is mainly from the Russian River, Dry Creek, and precipitation. Recharge is greatest on permeable soils and river channel deposits, which allow faster infiltration. In both Alexander Valley and the Healdsburg area, Russian River gains water from the surrounding sediments for most of the year, or until local ground water levels are sufficiently drawn down. When ground water levels are depressed, usually during fall, flow in Russian River recharges the ground water reservoir.

A program to determine the annual recharge rate would include measurements of rainfall, streamflow and soil permeability, and estimates of evapotranspiration. These figures would also provide information on when water percolates from the river into the ground water aquifer and when the aquifer supplies water to the river, as well as the amounts of such flow.

The estimates of soil permeability made by the Soil Conservation Service for the soil survey of Sonoma County (Miller, 1972) should be refined by examining wet weather percolation tests and conducting permeameter tests on each major soil type.

Water well drillers' reports submitted for wells built in the area should be reviewed annually. Deeper wells should be added to the monitoring network. Water yields, pump test information, and lithologic and electric logs from these deeper wells should be evaluated to increase understanding of the hydraulic characteristics of the ground water reservoir.

CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0 3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0 26417	3.7854
	megalitres	million gallons (10^6 gal)	0 26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35 315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0 26417	3 7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0 26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2 2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3 2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0 08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1 0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1 0	1 0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

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GLOSSARY

Acre-foot. The quantity of water needed to cover one acre to a depth of one foot equals 1.2385 cubic dekametres.

Agglomerate. A pyroclastic volcanic rock containing a predominance of rounded to subangular fragments greater than 32 mm in diameter.

Alluvial Fan Deposit. A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains upon the lowlands.

Alluvium. A geologic term describing unconsolidated beds of sand, silt, and clay deposited by flowing water.

Anion. A negatively charged ion, e.g., OH^-.

Anticline. A fold, generally convex upward, whose core contains the older rocks.

Aquiclude. A body of relatively impermeable rock that is capable of absorbing water slowly but functions as an upper or lower boundary of an aquifer and does not transmit ground water rapidly enough to supply a well or spring.

Aquifer. A subsurface water-bearing unit that transmits water rapidly enough to supply useful quantities to springs and wells. Sand and gravel aquifers are characterized by innumerable spaces around and among the grains. Water is stored in and moves through those spaces.

Aquifer Continuity. Hydraulic interconnection between and within aquifers so that ground water stored in one aquifer or portion of an aquifer is able to move into another aquifer or into another portion of an aquifer.

Artesian. An adjective referring to ground water confined under hydrostatic pressure.

Baseflow. Low flow in streams; occurs typically during long periods between precipitation when streamflow is maintained mostly or entirely by ground water discharge.

Brackish. Water that is intermediate in salt content between normal fresh water and normal sea water.

Breccia. A rock made up of highly angular, coarse, broken fragments.

Cation. A positively charged ion, e.g., H^+.

Chert. A compact siliceous rock of sedimentary origin.

Clay. A term which denotes either (1) particles regardless of mineral composition, with diameters less than 1/256 mm; or (2) a sediment composed primarily of these particles.

Coliform Bacteria. A type of bacteria found in soils and in the intestinal tracts of mammals. A hardy organism used as an indicator of contamination.

Confined. Refers to ground water under sufficient pressure to rise above the aquifer containing it when the aquifer is penetrated by a well. The difference between the water level in a well and the top of the aquifer is the Hydrostatic Head. Confined ground water is also known as Artesian.

Conglomerate. A cemented rock containing rounded fragments corresponding in size to gravel.

Conjunctive use. Planned management of surface and ground water resources as a single, interlocking system.

Connate Water. Water entrapped in the openings between particles of a sedimentary rock at the time the sediments were deposited. The water may be derived from either ocean water or land water.

Consolidated. Firm and coherent.

Constant-Rate Pump Test. Test pumping of a water well at a constant rate of discharge while the drop in the ground water level (drawdown) is recorded in a nearby observation well. The drawdown is plotted versus time since pumping began to determine Transmissivity, the rate at which ground water will flow through a unit width of the aquifer.

Contamination. Contamination means an impairment of the quality of the waters of the State by waste to a degree which creates a hazard to the public health through poisoning or through the spread of disease. Contamination includes any equivalent effect resulting from the disposal of waste, whether or not waters of the State are affected.

Continental Deposits. Sedimentary deposits laid down within a general land area and deposited in lakes or streams or by the wind; nonmarine deposits.

Cubic foot per second (cfs). A flow rate = 28.32 litres per second - 448,831 gallons per minute. Same as second feet or British cusec.

Diatomite. An earthy deposit composed of nearly pure silica and consisting of the shells of microscopic plants called diatoms.

Dip. The angle at which a planar feature is inclined from the horizontal.

Electrical Conductivity. A measure of the ease with which a conduction current can be caused to flow through a material under the influence of an applied electric field. Reciprocal of resistivity and measured in mhos per meter.

Evapotranspiration (ET). Loss of water from a land area through transpiration of plants and evaporation from plant surfaces and from the soil.

Fault. A fracture, or fracture zone, along which there has been displacement of the two sides relative to one another parallel to the fracture. This displacement may be a few inches or many miles. An *Active Fault* is one which has had surface displacement within Holocene time (about the last 11,000 years). The inverse of this, that other faults are inactive, is not necessarily true. A *Potentially Active Fault* is one which shows evidence of displacement during Quaternary time (last 2 to 3 million years).

Fault Plane. The more or less planar surface of a fault along which displacement has taken place.

Fault Trace. The surface expression of a fault.

Fault Zone. An area along the trace of a large fault consisting of numerous interlacing small faults or a zone of gouge or broken rock.

Fold. A bend in rock strata. An *Anticline* is a convex upward fold; it influences ground water by inducing flow away from the fold axis. A *Syncline* is a concave upward fold; it influences ground water by inducing flow toward the fold axis.

Formation. A geologic term that designates a specific group of beds or strata which have been deposited in sequence one above the other and during the same period of geologic time.

Fresh Water. Water that is not so affected by sea water intrusion, nitrate pollution, or other water quality problem, as to be detrimental for human use or consumption. Normal streamflow or ground water.

Gouge. Finely abraded material occurring between the walls of some faults, the result of grinding movement.

Gravel. A term which denotes either (1) particles regardless of mineral composition, with diameters greater than 2 mm; or (2) a sediment composed primarily of these particles. Gravel is frequently found as lens-shaped units within sandy deposits.

Greenstone. An altered basic igneous rock of greenish color due to the presence of such minerals as chlorite, hornblende, and epidote.

Ground Water Barrier. A body of material which is impermeable or slightly permeable which occurs below the land surface in such a position that it impedes the horizontal movement of ground water and consequently causes a pronounced difference in the level of the water table on opposite sides of it.

Ground Water Basin. An area underlain by one or more permeable formations capable of furnishing a substantial water supply. Usually, there is little movement of ground water from one basin to another.

Hydraulic Conductivity. The rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature or adjusted for a temperature of 60°F.

Hydraulics. The aspect of engineering that deals with the flow of water or other liquids.

Hydrograph. A graph showing the changes in the water level in a well with respect to time.

Hydrology. The science that relates to the distribution and phenomena of naturally occurring water.

Igneous. Rock formed from the solidification of molten material, either at depth or on the ground surface.

Infiltration. The flow or movement of surface water downward through the soil to become ground water.

Interbedded. Occurring between beds, or lying in a bed parallel to other beds of a different material.

Intrusive. Igneous rock which cools and solidifies below the earth's surface.

Ion. An electrically charged particle of matter dissolved in water. For instance, common table salt has no chemical charge. In water, salt "dissociates"; each molecule of salt (NaCl) forms one ion of sodium (Na^{+1}) with a positive charge, and one ion of chloride (Cl^{-1}) with a negative charge.

Kilogram (kg). A unit of weight = 1,000 grams = weight of one litre of pure water.

Limestone. A sedimentary rock consisting chiefly of calcium carbonate.

Litre (l). Metric measure of volume = 1,000 grams = 1,000 ml (millilitres). For pure water, one litre weighs one kilogram = 1,000 grams = 0.26 gal.

Marine Deposits. Sedimentary deposits laid down on the floor of the ocean.

Mathematical Model. A computer technique which simulates responses of a ground water basin to changes in recharge and pumping patterns. Used as a tool to predict future water levels under a variety of basin management plans.

Metamorphic. Rock which has been re-formed in the solid state in response to pronounced changes of temperature, pressure, and/or chemical environment and which takes place below the ground surface. A metamorphic rock originally was of a different form; i.e., it originally was igneous, sedimentary, or a different type of metamorphic rock.

Methmoglobinemia. A bluish or purplish discoloration (as of skin) due to deficient oxygenation of the blood which can be caused by excessive nitrates in drinking water.

Milliequivalent. A contraction of "milliequivalents per million", which is based on molecular weights; the units are "milligram equivalents per kilogram" if derived from data expressed in parts-per-million or "milligram equivalents per litre" if derived from data expressed in milligrams per

litre. In analyses expressed in milliequivalents, unit concentrations of all ions are chemically equivalent.

Milligram per litre (mg/L). One part by weight of dissolved chemical or suspended sediment, in one million parts by volume (= one litre) of water. Numerically equivalent to parts per million (ppm) between zero and about 7,000 mg/L.

Millilitre (ml). One one-thousandth of a litre = the volume of one gram of pure water.

Most Probable Number (MPN). A statistical evaluation of degree of water pollution based on presence of coliform bacteria. It is not feasible to identify the exact concentration of coliform bacteria in a water sample. The MPN interprets test results in terms of results observed. (See Coliform bacteria.)

Oxidation. The process of combining with oxygen; rust is a product of oxidation.

Parts per million (ppm). One part by weight of dissolved chemical, or suspended sediment, in one million parts by weight of water. Numerically equivalent to milligrams per litre (mg/L) between zero and about 7,000 ppm.

Percolation Rate. The rate at which water passes through the fine interstices in earth materials.

Permeability. The ability of a geologic material to transmit fluids such as water. The degree of permeability depends on the size and shape of the pore spaces and the extent, size, and shape of their interconnections.

Pollution. Pollution means an alteration of the quality of the waters of the State by waste to a degree which unreasonably affects (1) such waters for beneficial uses, or (2) facilities which serve such beneficial uses. Pollution may include contamination.

Potable. Drinkable; said of water and beverages.

Recharge. Replenishment of ground water by downward infiltration of water from rainfall, streams, and other sources. Natural Recharge is that recharge which occurs without assistance or enhancement by man. Artificial Recharge is that recharge which occurs when man deliberately modifies the natural recharge pattern to increase recharge.

Reduction. The process of removing oxygen; the opposite of oxidation.

Saline. Consisting of or containing salts (minerals), the most common of which are potassium, sodium, or magnesium in combination with chloride, nitrate, or carbonate.

Sand. A term which denotes either (1) particles with diameters ranging from 2 to 1/16 mm; or (2) a sediment composed primarily of these particles.

Scoria. Material ejected from a volcanic vent. Such material is usually vesicular, dark in color, heavy, and has a partly glassy-partly crystalline texture.

Sedimentary. Said of rocks formed from sediments. Includes such rock types as sandstone, conglomerate, shale, etc.

Serpentinite. A rock consisting almost entirely of the mineral serpentine, which is the alteration product of several types of ultrabasic rocks.

Silt. A term which denotes either (1) particles with diameters ranging from 1/16 to 1/256 mm; or (2) a sediment composed primarily of these particles.

Soil. A natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics.

Sorting. The degree of similarity, in respect to some particular characteristic (frequently size), of the component particles in a mass of material.

Specific Yield. The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass. This ratio is expressed as a percentage.

Storage Capacity. The volume of space below the land surface that can be used to store ground water. Total Storage Capacity is the total volume of space that could be used to store ground water. Available Storage Capacity is that volume of the total storage capacity that does not presently contain ground water and is therefore available to store recharged water.

Stream Gaging. The process by which the streamflow can be determined by measurement of the water level in the stream.

Sustained Yield. The volume of ground water that can be extracted annually from a ground water basin without causing a long-term drawdown in water level.

Syncline. A fold in which the core contains the younger rocks; it is generally concave upward.

Thermal Water. Hot or warm water.

Total Dissolved Solids (TDS). The quantity of minerals (salts) in solution in water, usually expressed in milligrams per litre or parts per million.

TRANSCAP. A computer program which determines transmissivity and storage capacity using specific yield data from individual wells. Averaged specific yield data are converted to transmissivities using equations of a curve developed by the DWR investigation of the Livermore and Sunol Valleys (Ford

and Hills, 1974). For specific yield values from 3 to 9, the curve is described by the equation:

$$\Delta T = \Delta D\ (10)^{x};$$

$$\text{where } x = \left[3.5319 - \frac{7.16288}{(SY) - 0.84} \right]$$

and for specific yield values greater than 9, by the equation:

$$\Delta T = \Delta D\ [100\ (SY) - 500]$$

where ΔT = incremental transmissivity (gallons/day/ft);

ΔD = incremental depth (ft); and

(SY) = percent value for average specific yield for a given interval.

Transmissivity. The rate of flow of water through each vertical strip of aquifer of unit width having a height equal to the saturated thickness of the aquifer and under a unit hydraulic gradient.

Tuff. A rock composed of compacted volcanic fragments smaller than 4 mm in diameter.

Unconformity. A surface of erosion that separates younger strata from older rocks; represents a substantial break or gap in the geologic record.

Water Table. (1) The upper surface of a zone of saturation except where that surface is formed by an impermeable body; (2) locus of points in soil water at which the pressure is equal to atmospheric pressure; (3) the surface where ground water is encountered in a well in an unconfined aquifer.

Well Log. A form filed with DWR by the driller of a water well which lists geologic materials encountered during drilling of the well, and information on the well's construction.

Zone of Saturation. A subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere.

Definitions Modified from the Following Sources

American Geological Institute, 1976, "Dictionary of Geological Terms", Revised Edition.

California Department of Water Resources, 1975, "California's Ground Water". Bulletin 118.

Ford, R. S., 1975, "Evaluation of Ground Water Resources: Sonoma County", California Department of Water Resources. Bulletin 118-4, Volume 1: "Geologic and Hydrologic Data".

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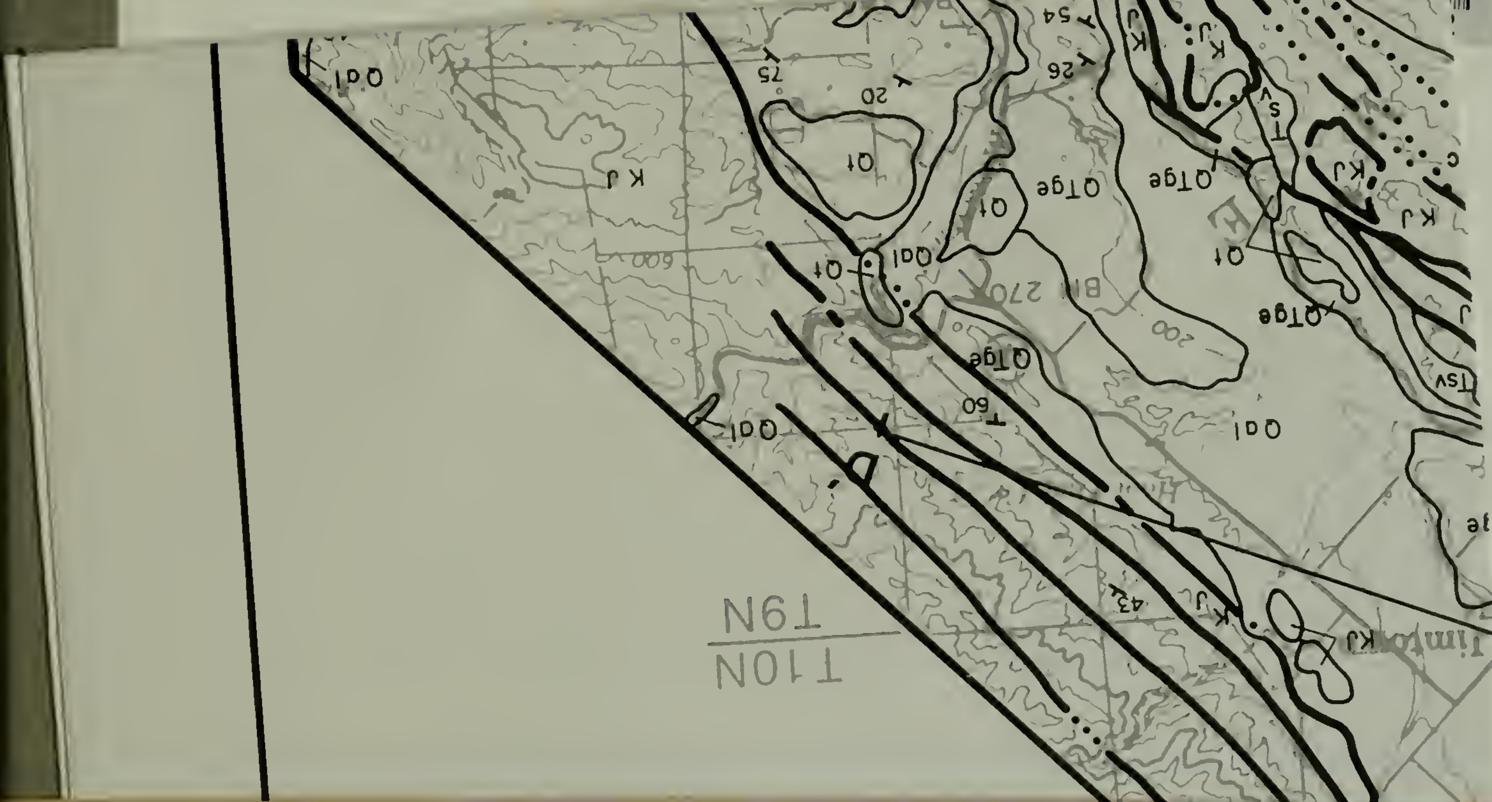
COLLATE.



GEOLOGY MODIFIED FROM THE FOLLOWING SOURCES:

Blake, M.C., et al, 1971, "Preliminary Geologic Map of Western Sonoma County and Northernmost Marin County". San Francisco Bay Region Environment and Resources Planning Study: U. S. Geological Survey. Basic Data Contribution 12.

Ford, R.S., 1975, "Evaluation of Ground Water Resources: Sonoma County". California Department of Water Resources. Bulletin 118-4, Volume 1: "Geologic and Hydrologic Data".

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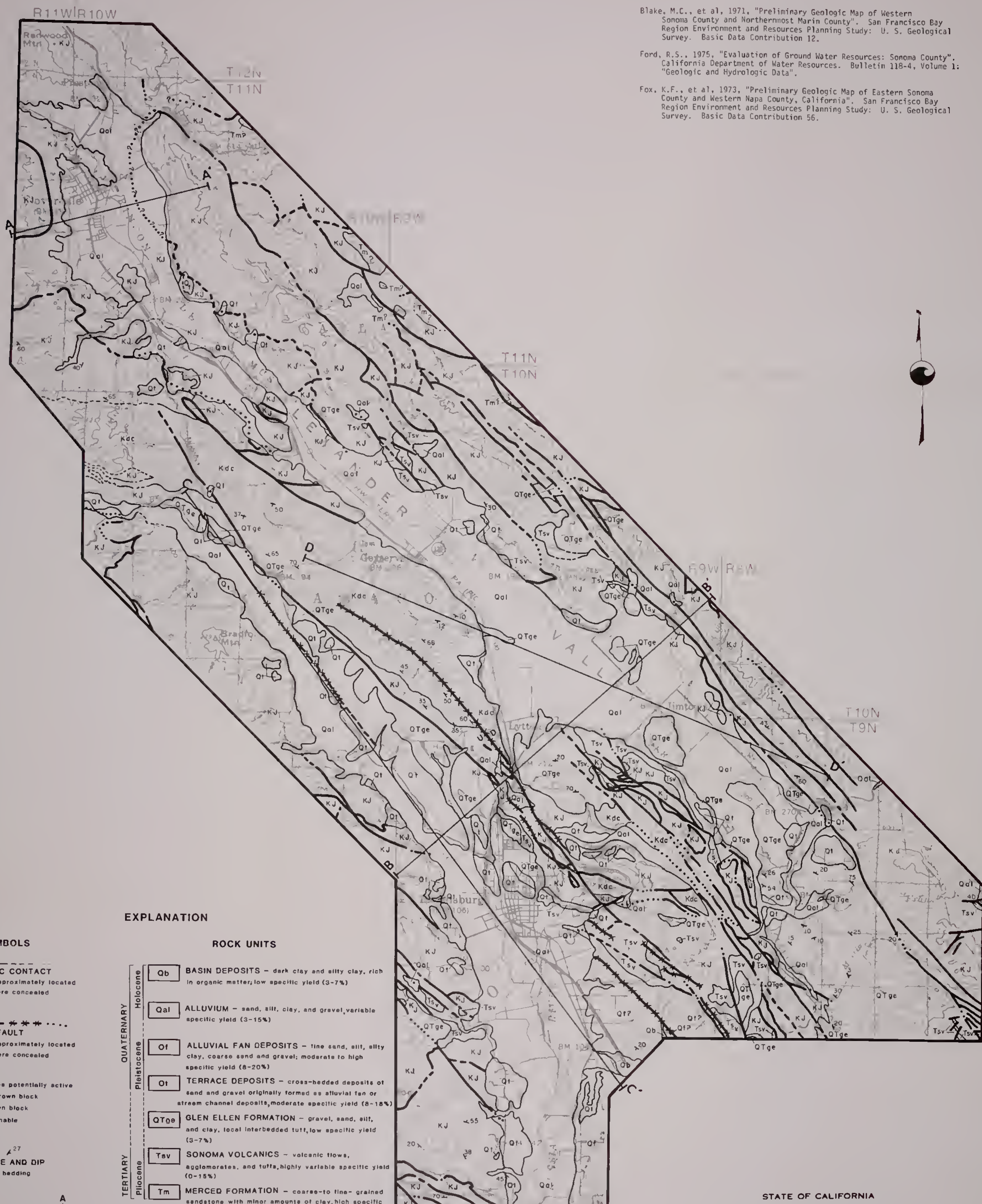

EXPLANATION

SYMBOLS

GEOLOGIC CONTACT
dashed where approximately located
dotted where concealed

FAULT
dashed where approximately located
dotted where concealed

x : indicates potentially active
D : downthrown block
U : upthrown block
? : questionable

27
STRIKE AND DIP
of bedding

A — A
LINE OF CROSS SECTION

ROCK UNITS

QUATERNARY	Holocene	Qb	BASIN DEPOSITS – dark clay and silty clay, rich in organic matter; low specific yield (3-7%)
		Qal	ALLUVIUM – sand, silt, clay, and gravel, variable specific yield (3-15%)
	Pleistocene	Qf	ALLUVIAL FAN DEPOSITS – fine sand, silt, silty clay, coarse sand and gravel; moderate to high specific yield (8-20%)
		Qt	TERRACE DEPOSITS – cross-bedded deposits of sand and gravel originally formed as alluvial fan or stream channel deposits, moderate specific yield (8-18%)
		QTge	GLEN ELLEN FORMATION – gravel, sand, silt, and clay, local interbedded tuff, low specific yield (3-7%)
TERTIARY	Pliocene	Tsv	SONOMA VOLCANICS – volcanic flows, agglomerates, and tuffs, highly variable specific yield (0-15%)
		Tm	MERCED FORMATION – coarse-to fine- grained sandstone with minor amounts of clay, high specific yield (10-20%)
JURA-CRETACEOUS		Kdc	DRY CREEK CONOLOMERATE – massive sheared cobble conglomerate with occasional interbeds of sandstone and shale, low specific yield (3-7%)
		KJ	FRANCISCAN COMPLEX – sandstone, shale, greenstone, chert, and serpentine includes great valley sequence rocks; low specific yield (<3%)

SCALE 1:62,500

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 KILOMETRES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY

GEOLOGY OF ALEXANDER VALLEY AND HEALDSBURG AREA

PLATE 1

GEOLOGY MODIFIED FROM THE FOLLOWING SOURCES:

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